Appendix A

System Descriptions

This appendix addresses the characteristics, capabilities, and limitations of existing and proposed common-use radionavigation systems. The systems covered are:

- Loran-C
- Omega
- VOR, VOR/DME, and TACAN
- ILS
- MLS
- Transit
- Aeronautical Radiobeacons
- Maritime Radiobeacons
- GPS
- Augmentations to GPS
- VTS

A.1 System Parameters

All of the systems described are defined in terms of system parameters which determine the use and limitations of the individual navigation system's signal in space. These parameters are:

- Signal Characteristics
- Accuracy
- Availability
- Coverage
- Reliability
- Fix Rate
- Fix Dimensions
- System Capacity
- Ambiguity
- Integrity

A.1.1 Signal Characteristics

Signals-in-space are characterized by power levels, frequencies, signal formats, data rates, and any other information sufficient to completely define the means by which a user derives navigational information.

A.1.2 Accuracy

In navigation, the accuracy of an estimated or measured position of a craft (vehicle, aircraft, or vessel) at a given time is the degree of conformance of that position with the true position of the craft at that time. Since accuracy is a statistical measure of performance, a statement of the accuracy of a navigation system is meaningless unless it includes a statement of the uncertainty in position which applies.

Statistical Measure of Accuracy

Navigation system errors generally follow a known error distribution. Therefore, the uncertainty in position can be expressed as the probability that the error will not exceed a certain amount. A thorough treatment of errors is complicated by the fact that the total error is comprised of errors caused by instability of the transmitted signal, effects of weather and other physical changes in the propagation medium, errors in the receiving equipment, and errors introduced by the human navigator. In specifying or describing the accuracy of a system, the human errors usually are excluded. Further complications arise because some navigation systems are linear (one-dimensional) while others provide two or three dimensions of position.

When specifying linear accuracy, or when it is necessary to specify requirements in terms of orthogonal axes (e.g., along-track or cross-track), the 95 percent confidence level will be used. Vertical or bearing accuracies will be specified in one-dimensional terms (2 sigma), 95 percent confidence level.

When two-dimensional accuracies are used, the 2 drms (distance root mean squared) uncertainty estimate will be used. Two drms is twice the radial error drms. The radial error is defined as the root-mean-square value of the distances from the true location point of the position fixes in a collection of measurements. It is often found by first defining an arbitrarily-oriented set of perpendicular axes, with the origin at the true location point. The variances around each axis are then found, summed, and the square root computed. When the distribution of errors is elliptical, as it often is for stationary, ground-based systems, these axes can be taken for convenience as the major and minor axes of the error ellipse. Then the confidence level depends on the elongation of the error ellipse. As the error ellipse collapses to a line, the confidence level of the 2 drms measurement approaches 95 percent; as the error ellipse becomes circular, the confidence level approaches 98 percent. The GPS 2 drms accuracy will be at 95 percent probability.

DOD specifies horizontal accuracy in terms of Circular Error Probable (CEP—the radius of a circle containing 50 percent of all possible fixes). For the FRP, the conversion of CEP to 2 drms has been accomplished by using 2.5 as the multiplier.

Types of Accuracy

Specifications of radionavigation system accuracy generally refer to one or more of the following definitions:

- Predictable accuracy: The accuracy of a radionavigation system's position solution with respect to the charted solution. Both the position solution and the chart must be based upon the same geodetic datum. (Note: Appendix B discusses reference systems and the risks inherent in using charts in conjunction with radionavigation systems).
- Repeatable accuracy: The accuracy with which a user can return to a position whose coordinates have been measured at a previous time with the same navigation system.
- Relative accuracy: The accuracy with which a user can measure position relative to that of another user of the same navigation system at the same time.

A.1.3 Availability

The availability of a navigation system is the percentage of time that the services of the system are usable by the navigator. Availability is an indication of the ability of the system to provide usable service within the specified coverage area. Signal availability is the percentage of time that navigational signals transmitted from external sources are available for use. It is a function of both the physical characteristics of the environment and the technical capabilities of the transmitter facilities.

A.1.4 Coverage

The coverage provided by a radionavigation system is that surface area or space volume in which the signals are adequate to permit the navigator to determine position to a specified level of accuracy. Coverage is influenced by system geometry, signal power levels, receiver sensitivity, atmospheric noise conditions, and other factors which affect signal availability.

A.1.5 Reliability

The reliability of a navigation system is a function of the frequency with which failures occur within the system. It is the probability that a system will perform its function within defined performance limits for a specified period of time under given operating conditions. Formally, reliability is one minus the probability of system failure.

A.1.6 Fix Rate

The fix rate is defined as the number of independent position fixes or data points available from the system per unit time.

A.1.7 Fix Dimensions

This characteristic defines whether the navigation system provides a linear, one-dimensional line-of-position, or a two-or three-dimensional position fix. The ability of the system to derive a fourth dimension (e.g., time) from the navigational signals is also included.

A.1.8 System Capacity

System capacity is the number of users that a system can accommodate simultaneously.

A.1.9 Ambiguity

System ambiguity exists when the navigation system identifies two or more possible positions of the vehicle, with the same set of measurements, with no indication of which is the most nearly correct position. The potential for system ambiguities should be identified along with provision for users to identify and resolve them.

A.1.10 Integrity

Integrity is the ability of a system to provide timely warnings to users when the system should not be used for navigation.

A.2 System Descriptions

This section describes the characteristics of those individual radionavigation systems currently in use or under development. These systems are described in terms of the parameters previously defined in Section A.1. All of the systems used for civil navigation are discussed. The systems which are used exclusively to meet the special applications of DOD are discussed in the CJCS MNP.

A.2.1 Loran-C

Loran-C was developed to provide DOD with a radionavigation capability having longer range and much greater accuracy than its predecessor, Loran-A. It was subsequently selected as the Federally provided radionavigation system for civil marine use in the U.S. coastal areas. For further Loran-C coverage information, consult the Loran-C Users Handbook (available from the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402).

A. Signal Characteristics

Loran-C is a pulsed, hyperbolic system operating in the 90 to 110 kHz frequency band. The system is based upon measurement of the difference in time of arrival of pulses of radio frequency (RF) energy radiated by a chain of synchronized transmitters which are separated by hundreds of miles. The measurements of time difference (TD) are made by a receiver which achieves high accuracy by comparing a zero crossing of a specified RF cycle within the pulses transmitted by master and secondary stations within a chain. Making this signal comparison early in the ground wave pulse assures that the measurement is made before the arrival of the corresponding sky waves. Precise control over the pulse shape ensures that the proper comparison point can be identified by the receiver. To aid in preventing sky waves from affecting TD measurements, the phase of the 100 kHz carrier of some of the pulses is changed in a predetermined pattern. Envelope matching of the signals is also possible but cannot provide the advantage of cycle comparison in obtaining the full system accuracy. The characteristics of Loran-C are summarized in Table A-1.

B. Accuracy

Within the published coverage area, Loran-C will provide the user who employs an adequate receiver with predictable accuracy of 0.25 nm (2 drms) or better. The repeatable accuracy of Loran-C is usually between 18 and 90 meters. Accuracy is dependent upon the Geometric Dilution of Precision (GDOP) factors at the user's location within the coverage area.

Loran-C navigation is predominantly accomplished using the ground wave signal. Sky wave navigation is feasible, but with considerable loss in accuracy. Ground waves and to some degree sky waves may be used for measuring time and time intervals. Loran-C was originally designed to be a hyperbolic navigation system. However, with the advent of the highly stable frequency standards, Loran-C can also be used in the range-range (rho-rho) mode of navigation. This is accomplished by a comparison of the received signal phase to a known time reference to determine propagation time and, therefore, range from the stations. It can be used in situations where the user is within reception range of individual stations, but beyond the hyperbolic coverage area. Because the position solution of GPS provides precise time, the interoperable use of rho-rho Loran-C with GPS appears to have merit.

The inherent accuracy of the Loran-C system makes it a suitable candidate for many land radiolocation applications. The purely numeric TD readings (no names, words, or narratives) are easy and efficient to both store and retrieve in automated form. Since the data are purely numeric, there can be none of the ambiguity that results from attempting to retrieve narrative descriptors from traffic accident reports and highway inventory data. While the 100 kHz signal is affected to some extent by soil

Table A-1. Loran-C System Characteristics (Signal-In-Space)

ACCURACY (2 drms)		AVAILABILITY	COVERAGE	RELIABILITY	FIX RATE	FIX DIMENSIONS	SYSTEM CAPACITY	AMBIGUITY POTENTIAL
PREDICTABLE	REPEATABLE							
0.25nm (460m) 1:3 SNR	60-300 ft. (18-90m)	99+%	U.S. coastal areas, continental U.S., selected overseas areas	99.7%*	10-20 fixes/min.	2D	Unlimited	Yes, easily resolved

* *Triad reliability.*

SYSTEM DESCRIPTION: Loran-C is a Low Frequency (LF) 100kHz hyperbolic radionavigation system. The receiver computes lines of position (LOP) based on the time of arrival difference between two time-synchronized transmitting stations of a chain. Three stations are required (master and two secondaries) to obtain a position fix in the normal mode of operation. Loran-C can be used in the Rho-Rho mode and accurate position data can be obtained with only two stations. Rho-Rho requires that the user platform have a precise clock. The United States is the primary provider of Loran-C coverage, although several nations in Europe and the Middle East have or are planning to initiate Loran-C service.

conductivity and terrain, it can be received in mountainous areas (where VHF and UHF systems can be terrain limited); however, some distortion of the hyperbolic grid has been noted. Propagation anomalies may be encountered in urban areas where the proximity of large manmade structures affects the signal. The existence of these anomalies is predictable and can be compensated for, usually by surveying the area. The long range of the Loran-C system makes it particularly desirable for application to remote areas, or where the user population is too low to justify the cost of a large number of short-range facilities.

By monitoring Loran-C signals at a fixed site, the receiver TD can be compared with a computed TD for the known location of the site. A correction for the area can then be broadcast to users. This technique (called differential Loran-C), whereby real-time corrections are applied to Loran-C TD readings, provides improved accuracy. Although this can improve Loran-C's absolute accuracy features, no investment in this approach to enhancing Loran-C's performance is anticipated by the Federal Government.

Loran-C signal monitors have been installed throughout the NAS to support the use of Loran-C as a nonprecision approach aid. The monitors will be operated and maintained by the FAA. Each monitor will provide long-term signal data for use in the prediction of signal corrections at individual airports. Predicted corrections will be published periodically with approach procedures. Signal status information will be used by air traffic personnel as necessary.

Loran-C receivers are available at a relatively low cost and achieve the 0.25 nm (2 drms) accuracy that Loran-C provides at the limits of the coverage area. A modern Loran-C receiver automatically acquires and tracks the Loran-C signal and is useful to the limits of the specified Loran-C coverage areas.

C. Availability

The Loran-C transmitting equipment is very reliable. Redundant transmitting equipment is used to reduce system downtime. Loran-C transmitting station signal availability is greater than 99.9 percent, providing 99.7 percent triad availability.

D. Coverage

The Loran-C system has been expanded over the years to meet the requirements for coverage of the U.S. coastal waters and the conterminous 48 states, the Great Lakes, the Gulf of Alaska, the Aleutians, and into the Bering Sea. Based on DOD requirements, the USCG also operates Loran-C stations in the Far East, Northern Europe, and the Mediterranean Sea. Loran-C coverage as it will be operated and supported by the USCG after January 1, l995 is shown in Figure A-1.

Expansion of the Loran-C system into the Caribbean Sea, the North Slope of Alaska, and Eastern Hawaii has been investigated. Studies have shown, however, that the

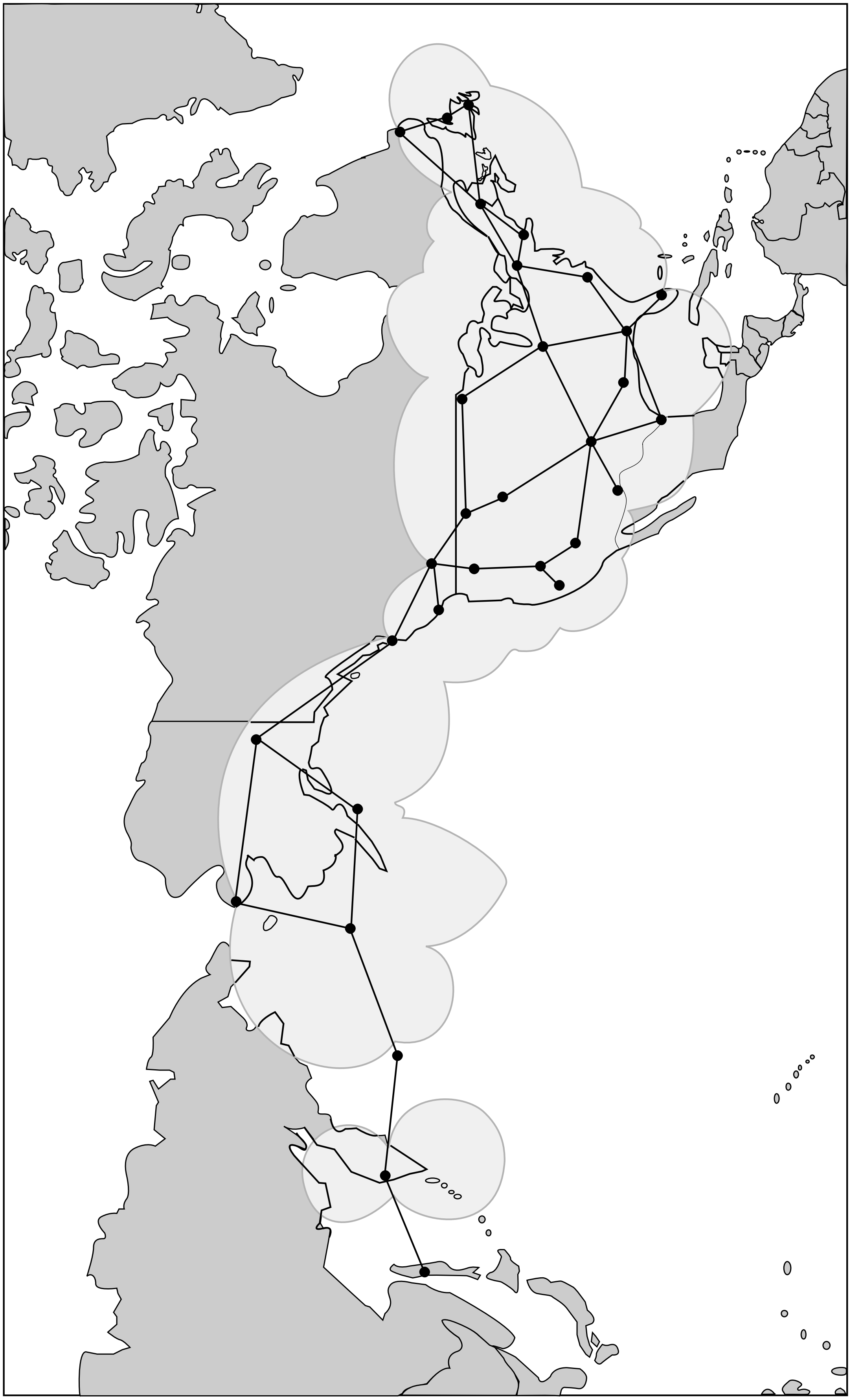

Figure A-1. Coverage Provided by U.S. Operated or Supported Loran-C Stations

benefit/cost ratio is currently insufficient to justify expansion of Loran-C into any of these areas.

E. Reliability

Loran-C stations are constantly monitored. The accuracy of system timing is maintained to half the system tolerance. Stations which exceed the system tolerance are "blinked." Blink is the on-off pattern of the first two pulses of the secondary signal indicating that a baseline is unusable. System tolerance within the U.S. is $\pm$100 nanoseconds of the calibrated control value. Individual station reliability normally exceeds 99.9 percent, resulting in triad availability exceeding 99.7 percent. The introduction of the Automatic Blink System into the NAS will automate the method to initiate system blink. Once installed, "blink" will occur within ten seconds of a timing abnormality at a secondary station and in the case of a Master station timing abnormality, the signal will be taken off-air until the situation has been corrected or until all of the secondaries are blinking.

F. Fix Rate

The fix rate available from Loran-C ranges from 10 to 20 fixes per minute.

G. Fix Dimensions

Loran-C will furnish two or more lines of position (LOPs) to provide a two-dimensional fix.

H. System Capacity

An unlimited number of receivers may use Loran-C simultaneously.

I. Ambiguity

As with all hyperbolic systems, theoretically, the LOPs may cross at more than one position on the earth. However, because of the design of the coverage area, the ambiguous fix is at a great distance from the desired fix and is easily resolved.

J. Integrity

Loran-C stations are constantly monitored to detect signal abnormalities which would render the system unusable for navigation purposes. The secondary stations "blink" to notify the user that a master-secondary pair is unusable. Blink begins immediately upon detection of an abnormality. The USCG and the FAA are also developing automatic blink equipment and a concept of operations based on factors consistent with aviation use. Once automatic blink equipment is installed in the NAS, secondary blink will be initiated within ten seconds of a timing abnormality and in the case of a Master station, the signal will be taken off-air until the problem is corrected and all secondaries are blinking.

A.2.2 Omega

The Omega system initially was proposed to meet a DOD need for worldwide general en route navigation but has now evolved into a system used primarily by the civil community. The system is comprised of eight continuous wave (CW) transmitting stations situated throughout the world. Worldwide position coverage was attained when the station in Australia became operational in l982. For further information, contact the U.S. Coast Guard's Navigation Center (NAVCEN), 7323 Telegraph Road, Alexandria, Virginia, 22315-3998 by mail, or telephone 703-313-5900 (voice), 703-313-5920 (fax), or 703-313-5906 (Omega status recording). Omega information can also be obtained via the Navigation Information Center Bulletin Board Service.

A. Signal Characteristics

Omega utilizes CW phase comparison of signal transmission from pairs of stations. The stations transmit time-shared signals on four frequencies, in the following order: 10.2 kHz, 11.33 kHz, 13.6 kHz, and 11.05 kHz. In addition to these common frequencies, each station transmits a unique frequency to aid station identification and to enhance receiver performance. The signal characteristics of Omega are summarized on Table A-2. For further information on the Omega systems, consult the Omega User's Guide (available from the USCG Navigation Center, 7323 Telegraph Road, Alexandria, Virginia 22315-3998).

B. Accuracy

The inherent accuracy of the Omega system is limited by the accuracy of the propagation corrections that must be applied to the individual receiver readings. The corrections may be in the form of predictions from tables which can be applied to manual receivers or may be stored in memory and applied automatically in computerized receivers. The system was designed to provide a predictable accuracy of 2 to 4 nm (2 drms). That accuracy depends on location, station pairs used, time of day, and validity of the propagation corrections.

Propagation correction tables and formulas are based on theoretical models calibrated to fit worldwide monitor data taken over long periods. A number of permanent monitors are maintained to assess the system accuracy on a long-term basis. The system currently provides coverage over most of the Earth. The specific accuracy attained depends on the type of equipment used as well as the time of day and the location of the user. In most cases, the accuracies attained are consistent with the 2 to 4 nm system design goal and in some cases much better accuracy is reported. A validation program conducted by the USCG indicated that the Omega system meets its design goal of 2 to 4 nm accuracy.

Although not part of any current U.S. effort, a differential Omega system has been developed and there are now differential stations in operation along the coast of

Table A-2. Omega System Characteristics (Signal-In-Space)

ACCURACY (2 drms)			AVAILABILITY	COVERAGE	RELIABILITY	FIX RATE	FIX DIMENSION	SYSTEM CAPACITY	AMBIGUITY POTENTIAL
PREDICTABLE	REPEATABLE	RELATIVE*							
2-4 nm (3.7-7.4km)	2-4nm (3.7-7.4km)	0.25-0.5nm (463-926m)	99+%	Worldwide continuous	97%*	1 fix to every 10 seconds	2D	Unlimited	Requires knowledge to ±36nm**

* *Three station joint signal availability.*

** *Three frequency receiver (10.2, 11.33, 13.6kHz).*

SYSTEM DESCRIPTION: Omega is a Very Low Frequency (VLF) 10.2 - 13.6kHz hyperbolic radionavigation system. There are eight transmitting stations. Position information is obtained by measuring relative phase difference of received Omega signals. The system is multinational, operated by seven nations, with day-to-day operational control exercised by the U.S. Coast Guard.

Europe, in the Mediterranean, and in Southeast Asia areas. Differential Omega stations operate on the principle of a local area monitor system comparing the received Omega signal with the predicted signal for the location and then transmitting a correction factor based on the observed difference. The correction factor is usually transmitted over an existing radiobeacon system and can provide an accuracy ranging from 0.3 nm at 50 miles to 1 nm at 500 miles. The range of transmission of the correction factor varies with the range of the beacon, but is roughly three times the advertised range of the beacon. Reception of the differential Omega signal requires the use of a differential Omega receiver.

C. Availability

Exclusive of infrequent periods of scheduled off-air time for maintenance, Omega availability is greater than 99 percent per year for each station and 95 percent for three stations. Annual system availability has been greater than 97 percent with scheduled off-air time included.

D. Coverage

Omega provides essentially worldwide coverage.

E. Reliability

Omega system design requirements for reliability called for 99 percent single station availability and 95 percent three-station joint signal availability. Three-station joint signal availability exceeds 97 percent, including both emergency shutdowns and scheduled off-air periods.

F. Fix Rate

Omega provides independent positional fixes once every ten seconds.

G. Fix Dimensions

Omega will furnish two or more LOPs to provide a two-dimensional fix.

H. System Capacity

An unlimited number of receivers may be used simultaneously.

I. Ambiguity

In this CW system, ambiguous LOPs occur since there is no means to identify particular points of constant phase difference which recur throughout the coverage area. The area between lines of zero phase difference are termed “lanes.” Single-frequency receivers use the 10.2 kHz signals whose lane width is about eight nautical miles on the baseline between stations. Multiple-frequency receivers extend the lane width, for the purpose of resolving lane ambiguity. Lane widths of approximately 288 nm along the baseline can be generated with a four-frequency receiver. Because of the lane ambiguity, a receiver must be preset to a known location at the start of a voyage. The accuracy of that position must be known with sufficient accuracy to be within the lane that the receiver is capable of generating (i.e., 4 nm for a single-frequency receiver or approximately 144 nm for a four-frequency receiver). Once set to a known location, the Omega receiver counts the number of lanes it crosses in the course of a voyage. This lane count is subject to errors which may be introduced by an interruption of power to the receiver, changes in propagation conditions near local sunset and sunrise, and other factors. To use the single frequency Omega receiver effectively for navigation, it is essential that a DR plot or similar means be carefully maintained and the Omega positions compared to it periodically so that any lane ambiguities can be detected and corrected.

The accuracy of an Omega phase-difference measurement is independent of the elapsed time or distance since the last update. Unless the Omega position is verified occasionally by comparison to a fix obtained with another navigation system or by periodic comparison to a carefully maintained plot, the chance of an error in the Omega lane count increases with time and distance. These errors are reduced in multiple frequency receivers since they are capable of developing larger lane widths to resolve ambiguity problems.

J. Integrity

Omega transmissions are monitored constantly to detect signal abnormalities that affect the useable coverage area. Emergency advisories for unplanned status changes (reduced power, off-airs, Polar Cap Absorption, etc.) are provided by the Navigation Center within 24 hours. This notification is distributed by the National Bureau of Standards (WWV/WWVH announcements), Broadcast Notice to Mariners, Notice to Airmen, HYDROLANT/HYDROPAC messages through the Navigation Information Services, and recorded telephone messages. Scheduled off-air periods are announced up to 30 days before the off-air is to occur using the same distribution mechanisms as for unplanned status changes.

A.2.3 VOR, VOR/DME, and TACAN

The three systems that provide the basic guidance for en route air navigation in the United States are VOR, DME, and TACAN. Information provided to the aircraft pilot by VOR is the azimuth relative to the VOR ground station. DME provides a measurement of distance from the aircraft to the DME ground station. In most cases, VOR and DME are collocated as a VOR/DME facility. TACAN provides both azimuth and distance information and is used primarily by military aircraft. When TACAN is collocated with VOR, it is a VORTAC facility. DME and the distance measuring function of TACAN are the same.

I. VOR

A. Signal Characteristics

VORs are assigned frequencies in the 108 to 118 MHz frequency band, separated by 100 kHz. A VOR transmits two 30 Hz modulations resulting in a relative electrical phase angle equal to the azimuth angle of the receiving aircraft. A cardioid field pattern is produced in the horizontal plane and rotates at 30 Hz. A nondirectional (circular) 30 Hz pattern is also transmitted during the same time in all directions and is called the reference phase signal. The variable phase pattern changes phase in direct relationship to azimuth. The reference phase is frequency modulated while the variable phase is amplitude modulated. The receiver detects these two signals and computes the azimuth from the relative phase difference. For difficult siting situations, a system using the Doppler effect was developed and uses 50 instead of four antennas for the variable phase. The same avionics works with either type ground station. The signal characteristics of VOR are summarized in Table A-3.

B. Accuracy (2 sigma)

- Predictable - The ground station errors are approximately ±1.4 degrees. The addition of course selection, receiver and flight technical errors, when combined using root-sum-squared (RSS) techniques, is calculated to be ±4.5 degrees.

- Relative - Although some course bending could influence position readings between aircraft, the major relative error consists of the course selection, receiver and flight technical components. When combined using RSS techniques, the value is approximately ±4.3 degrees. The VOR ground station relative error is ±0.35 degrees.

- Repeatable - The major error components of the ground system and receiver will not vary appreciably in the short term. Therefore, the repeatable error will consist mainly of the flight technical error (the pilots' ability to fly the system) which is ±2.3 degrees.

C. Availability

Because VOR coverage is overlapped by adjacent stations, the availability is considered to approach 100 percent for new solid state equipment.

D. Coverage

VOR has line-of-sight limitations which could limit ground coverage to 30 miles or less. At altitudes above 5,000 feet, the range is approximately 100 nm, and above 20,000 feet, the range will approach 200 nm. These stations radiate approximately 200 watts. Terminal VOR stations are rated at approximately 50 watts and are only

Table A-3. VOR and VOR/DME System Characteristics (Signal-In-Space)

ACCURACY (2 Sigma)									
PREDICTABLE	REPEATABLE	RELATIVE	AVAILABILITY	COVERAGE	RELIABILITY	FIX RATE	FIX DIMENSIONS	SYSTEM CAPACITY	AMBIGUITY POTENTIAL
VOR: 90m ($\pm$1.4°)*	23m ($\pm$0.35°)**	--	Approaches 100%	Line of sight	Approaches 100%	Continuous	Heading in degrees or angle off course	Unlimited	None
DME: 185m ($\pm$0.1nm)	185m ($\pm$0.1nm)	--					Slant range (nm)	100 users per site, full service	

* *The flight check of published procedures for the VOR signal is $\pm$1.4°. The ground monitor turns the system off if the signal exceeds $\pm$1.0°. The cross-track error used in the chart is for $\pm$1.4° at 2nm from the VOR site. However, some uses of VOR are overhead and/or 1/2nm from the VOR.*

* *Test data shows that 99.94% of the time the error is less than $\pm$.35°. These values are for $\pm$.35° at 2nm from the VOR.*

SYSTEM DESCRIPTION: VOR provides aircraft with bearing information relative to the VOR signal and magnetic north. The system is used for landing, terminal, and en route guidance. VOR transmitters operate in the VHF frequency range. DME provides a measurement of distance from the aircraft to the DME ground station. DME operates in the UHF frequency range.

intended for use within the terminal areas. Actual VOR coverage information is contained in FAA Order 1010.55C.

E. Reliability

Due to advanced solid state construction and the use of remote maintenance monitoring techniques, the reliability of solid state VOR approaches 100 percent.

F. Fix Rate

This system allows a continuous update of deviation from a selected course. Initialization is less than one minute after turn-on and will vary as to receiver design.

G. Fix Dimensions

The system shows magnetic bearing to a VOR station and deviation from a selected course, in degrees.

H. System Capacity

The capacity of a VOR station is unlimited.

I. Ambiguity

There is no ambiguity possible for a VOR station.

J. Integrity

VOR provides system integrity by removing a signal from use within ten seconds of an out-of-tolerance condition detected by an independent monitor.

II. DME

A. Signal Characteristics

The interrogator in the aircraft generates a pulsed signal (interrogation) which, when of the correct frequency and pulse spacings, is accepted by the transponder. In turn, the transponder generates pulsed signals (replies) which are sent back and accepted by the interrogator's tracking circuitry. Distance is then computed by measuring the total round trip time of the interrogation and its reply. The operation of DME is thus accomplished by paired pulse signals and the recognition of desired pulse spacings accomplished by the use of a decoder. The transponder must reply to all interrogators. The interrogator must measure elapsed time between interrogation and reply pulse pairs and translate this to distance. All signals are vertically polarized. These systems are assigned in the 960 to 1,213 MHz frequency band with a separation of 1 MHz.

The capability to use Y-channel service has been developed and implemented to a very limited extent (approximately 15 DMEs paired with localizers use the Y-channel frequencies). The term "Y-channel" refers to VOR frequency spacing. Normally, X-channel frequency spacing of 100 kHz is used. Y-channel frequencies are offset from the X-channel frequencies by 50 kHz. In addition, Y-channel DMEs are identified by a wider interrogation pulse-pair time spacing of 0.036 msec versus X-channel DMEs at 0.012 msec spacing. X- and Y-channel applications are presently limited to minimize user equipment changeovers. The signal characteristics of DME are summarized in Table A-3.

B. Accuracy (2 sigma)

- Predictable - The ground station errors are less than ±0.1 nm. The overall system error (airborne and ground RSS) is not greater than ±0.5 nm or 3 percent of the distance, whichever is greater.
- Relative - Although some errors could be introduced by reflections, the major relative error emanates from the receiver and flight technical error.
- Repeatable - Major error components of the ground system and receiver will not vary appreciably in the short term.

C. Availability

The availability of DME is considered to approach 100 percent, with positive indication when the system is out-of-tolerance.

D. Coverage

DME has a line-of-sight limitation, which limits ground coverage to 30 nm or less. At altitudes above 5,000 feet, the range will approach 100 nm. En route stations radiate at 1,000 watts. Terminal DMEs radiate 100 watts and are only intended for use in terminal areas.

E. Reliability

With the use of solid state components and remote maintenance monitoring techniques, the reliability of the DME approaches 100 percent.

F. Fix Rate

The system essentially gives a continuous update of distance to the facility. Actual update rate varies with the design of airborne equipment and system loading.

G. Fix Dimensions

The system shows slant range to the DME station in nm.

H. System Capacity

For present traffic capacity 110 interrogators are considered reasonable. Future traffic capacity could be increased when necessary through reduced individual aircraft interrogation rates and removal of beacon capacity reply restrictions.

I. Ambiguity

There is no ambiguity in the DME system.

J. Integrity

DME provides system integrity by removing a signal from use within ten seconds of an out-of-tolerance condition detected by an independent monitor.

III. TACAN

A. Signal Characteristics

TACAN is a short-range UHF (960 to 1,215 MHz) radionavigation system designed primarily for aircraft use. TACAN transmitters and responders provide the data necessary to determine magnetic bearing and distance from an aircraft to a selected station. TACAN stations in the U.S. are frequently collocated with VOR stations. These facilities are known as VORTACs. The signal characteristics of TACAN are summarized in Table A-4.

B. Accuracy (2 sigma)

- Predictable - The ground station errors are less than ±1.0 degree for azimuth for the 135 Hz element and ±4.5 degrees for the 15 Hz element. Distance errors are the same as DME errors.
- Relative - The major relative errors emanate from course selection, receiver and flight technical error.
- Repeatable - Major error components of the ground station and receiver will not vary greatly in the short term. The repeatable error will consist mainly of the flight technical error.

C. Availability

The availability of TACAN service is considered to approach 100 percent.

D. Coverage

TACAN has a line-of-sight limitation which limits ground coverage to 30 nm or less. At altitudes of 5,000 feet the range will approach 100 nm; above 18,000 feet, the range approaches 200 nm. The station output power is 5 kW.

Table A-4. TACAN System Characteristics (Signal-In-Space)

ACCURACY (2 Sigma)			AVAILABILITY	COVERAGE	RELIABILITY	FIX RATE	FIX DIMENSIONS	SYSTEM CAPACITY	AMBIGUITY POTENTIAL
PREDICTABLE	REPEATABLE	RELATIVE							
Azimuth ±1° (± 63m at 3.75km)	Azimuth ±1° (± 63m at 3.75km)	Azimuth ±1° (±63m at 3.75km)	98.7%	Line of sight	99%	Continuous	Distance and bearing from station	110 for distance. Unlimited in azimuth	No ambiguity in range. Sight potential for ambiguity at multiples of 40°
DME: 185m (±0.1nm)	DME: 185m (±0.1nm)	DME: 185m (±0.1nm)							

SYSTEM DESCRIPTION: TACAN is a short-range UHF navigation system used by the military. The system provides range, bearing and station identification. When TACAN is collocated with a VOR it is called a VORTAC facility.

E. Reliability

With the use of solid state electronics and remote maintenance monitoring techniques, the reliability of the TACAN system approaches 100 percent.

F. Fix Rate

TACAN provides a continuous update of the deviation from a selected course. Initialization is less than one minute after turn on. Actual update rate varies with the design of airborne equipment and system loading.

G. Fix Dimensions

The system shows magnetic bearing, deviation in degrees, and distance to the TACAN station in nautical miles.

H. System Capacity

For distance information, 110 interrogators are considered reasonable for present traffic handling. Future traffic handling could be increased when necessary through reduced airborne interrogation rates and increased reply rates. Capacity for the azimuth function is unlimited.

I. Ambiguity

There is no ambiguity in the TACAN range information. There is a slight probability of azimuth ambiguity at multiples of 40 degrees.

J. Integrity

TACAN provides system integrity by removing a signal from use within ten seconds of an out-of-tolerance condition detected by an independent monitor.

A.2.4 ILS

ILS is a precision approach system normally consisting of a localizer facility, a glide slope facility, and two or three VHF marker beacons. It provides vertical and horizontal navigational (guidance) information during the approach to landing at an airport runway.

At present, ILS is the primary worldwide, ICAO-approved, precision landing system. This system is presently adequate, but has limitations in siting, frequency allocation, cost, and performance.

A. Signal Characteristics

The localizer facility and antenna are typically located 1,000 feet beyond the stop end of the runway and provides a VHF (108 to 112 MHz) signal. The glide slope facility is located approximately 1,000 feet from the approach end of the runway and provides a UHF (328.6 to 335.4 MHz) signal. Marker beacons are located along an extension of the runway centerline and identify particular locations on the approach. Ordinarily, two 75 MHz beacons are included as part of the instrument landing system: an outer marker at the initial approach fix (typically four to seven miles from the approach end of the runway) and a middle marker located 3,500 feet plus or minus 250 feet from the runway threshold. The middle marker is located so as to note impending visual acquisition of the runway in conditions of minimum visibility for Category I ILS approaches. An inner marker, located approximately 1,000 feet from the threshold, is normally associated with Category II and III ILS approaches. The signal characteristics of ILS are summarized in Table A-5.

B. Accuracy

For typical air carrier operations at a 10,000 foot runway, the course alignment (localizer) at threshold is maintained within $\pm$25 feet. Course bends during the final segment of the approach do not exceed $\pm$0.06 degrees (2 sigma). Glide slope course alignment is maintained within $\pm$7.0 feet at 100 feet (2 sigma) elevation and glide path bends during the final segment of the approach do not exceed $\pm$0.07 degrees (2 sigma).

C. Availability

To further improve the availability of service from ILS installations, vacuum tube equipment has been replaced with solid state equipment. Service availability is now approaching 99 percent.

D. Coverage

Coverage for individual systems is as follows:

Localizer: $\pm 2^{o}$ centered about runway centerline.

Glide Slope: Nominally 3^{o} above the horizontal.

Marker Beacons: $\pm 40^{o}$ (approximately) on minor axis (along approach path) $\pm 85^{o}$ (approximately) on major axis.

E. Reliability

ILS reliability approaches 100 percent. However, terrain and other factors may impose limitations upon the use of the ILS signal. Special account must be taken of terrain factors and dynamic factors such as taxiing aircraft which can cause multipath signal transmissions.

In some cases, to resolve ILS siting problems, use has been made of localizers with wide aperture antennas and two-frequency systems. In the case of the glide slope,

Table A-5. ILS Characteristics (Signal-In-Space)

ACCURACY AT DECISION HEIGHT (Meters - 2 Sigma)									
CATEGORY	AZIMUTH	ELEVATION	AVAILABILITY	COVERAGE	RELIABILITY	FIX RATE	FIX DIMENSION	SYSTEM CAPACITY	AMBIGUITY POTENTIAL
1	$\pm$9.1	$\pm$3.0	Approaches 100%	Normal limits from center of localizer $\pm 10^{o}$ out to 18nm and $\pm 35^{o}$ out to 10nm	98.6% with positive indication when the system is out of tolerance	Continuous	Heading and deviation in degrees	Limited only by aircraft separation requirements	None
2	$\pm$4.6	$\pm$1.4							
3	$\pm$4.1	$\pm$0.4							

* *Signal availability in the coverage volume.*

SYSTEM DESCRIPTION: The Instrument Landing System (ILS) is a precision approach system consisting of a localizer facility, a glide scope facility and two or three VHF marker beacons. The VHF (108-112Mhz) localizer facility provides accurate, single path horizontal guidance information. The UHF (328.6-335.4Mhz) glide scope provides precise, single path, vertical guidance information to a landing aircraft.

use has been made of wide aperture, two-frequency image arrays and single-frequency broadside arrays to provide service at difficult sites.

F. Fix Rate

The glide slope and localizer provide continuous fix information. Marker beacons which provide an audible and visual indication to the pilot are sited at specific points along the approach path as indicated in Table A-6.

Table A-6. Aircraft Marker Beacons

MARKER DESIGNATION	TYPICAL DISTANCE TO THRESHOLD	AUDIBLE SIGNAL	LIGHT COLOR
Outer	4-7nm	Continuous dashes (2/sec)	Blue
Middle	3,250-3,750 ft	Continuous alternating dot-dash	Amber
Inner	1,000 ft	Continuous dots (6/sec)	White

G. Fix Dimensions

ILS provides both vertical and horizontal guidance with glide slope and localizer signals. At periodic intervals (passing over marker beacons) distance to threshold is obtained.

H. System Capacity

ILS has no capacity limitations except those imposed by aircraft separation requirements since aircraft must be in trail to use the system.

I. Ambiguity

Any potential ambiguities are resolved by imposing system limitations as described in Section A.2.4.E.

J. Integrity

ILS provides system integrity by removing a signal from use when an out-of-tolerance condition is detected by an integral monitor. The shutdown delay for each category is given below:

Shutdown Delay

	Localizer	Glide Slope
CAT I	<10 sec	<6 sec
CAT II	<5 sec	<2 sec
CAT III	<2 sec	<2 sec

A.2.5 MLS

MLS provides a common civil/military landing system to meet the full range of user operational requirements, as defined in the ICAO list of 38 operational requirements for precision approach and landing systems, to the year 2000 and beyond. It was originally intended to be a replacement for ILS, used by both civil and military aircraft, and the Ground Controlled Approach (GCA) system used primarily by military operators. However, DGPS systems are now envisioned to satisfy the majority of requirements originally earmarked for MLS.

The FAA has terminated all R,E&D activity associated with MLS and has limited deployment to approximately 30 Category I sites at airports supporting international operations that can be satisfied with MLS systems manufactured through June 1994. The role of MLS in support of Category II and III requirements is to be determined pending architectural decisions scheduled for late 1995.

For those MLS systems that are ultimately deployed, the MLS signal is transmitted throughout a large volume of airspace, thereby permitting service to multiple aircraft, along multiple approach paths, throughout the approach, flare, touchdown, and rollout maneuvers. The system permits greater flexibility in air traffic procedures, enhancing safety, and permits curved and segmented approach paths for purposes of noise abatement. MLS allows steep glide path approaches for airports in mountainous terrain, and facilitates short field operations for short and/or vertical takeoff and landing (STOL and VTOL) aircraft.

A. Signal Characteristics

MLS transmits signals that enable airborne units to determine the precise azimuth angle, elevation angle, and range. The technique chosen for the angle function of the MLS is based upon Time-Referenced Scanning Beams (TRSB). All angle functions of MLS operate in the 5.00 to 5.25 GHz band. Ranging is provided by DME operating in the 0.96 to 1.215 GHz band. An option is included in the signal format to permit a special purpose system to operate in the 15.4 to 15.7 GHz band. The system characteristics of MLS are summarized in Table A-7.

Table A-7. MLS Characteristics (Signal-In-Space)

ACCURACY AT DECISION HEIGHT (Meters - 2 Sigma)									
CATEGORY	AZIMUTH	ELEVATION	AVAILABILITY	COVERAGE	RELIABILITY	FIX RATE**	FIX DIMENSION	SYSTEM CAPACITY	AMBIGUITY POTENTIAL
1	±9.1	±3.0	Expected to approach 100%	40° from center line of runway out to 20nm in both directions*	Expected to approach 100%	6.5-39 fixes/sec depending on function	Heading and deviation in degrees. Range in nm	Limited only by aircraft separation requirements	None
2	±4.6	±1.4							
3	±4.1	±0.4							

* *There are provisions for 360° out to 20nm.*

SYSTEM DESCRIPTION: The Microwave Landing System (MLS) is a precision landing system that will operate in the 5-5.25 GHz band. Ranging is provided by precis ion DME operating in .96-1.22 GHz band.

B. Accuracy (2 sigma)

The azimuth accuracy is $\pm$13.0 feet ($\pm$4.0m) at the runway threshold approach reference datum and the elevation accuracy is $\pm$2.0 feet ($\pm$0.6m). The lower surface of the MLS beam crosses the threshold at 8 feet (2.4 meters) above the runway centerline. The flare guidance accuracy is $\pm$1.2 feet throughout the touchdown zone and the DME accuracy is $\pm$100 feet for the precision mode and $\pm$1,600 feet for the nonprecision mode.

C. Availability

Equipment redundancy, as well as remote maintenance monitoring techniques, should allow the availability of this system to approach 100 percent.

D. Coverage

Current plans call for the installation of systems with azimuthal coverage of $\pm 40^{o}$ on either side of the runway centerline, elevation coverage from 0^{o} to a minimum of 15^{o} over the azimuthal coverage area, and out to 20 nm. A few systems will have $\pm 60^{o}$ azimuthal coverage. MLS signal format has the capability of providing coverage to the entire 360^{o} area but with less accuracy in the area outside the primary coverage area of $\pm 60^{o}$ of runway centerline. There will be simultaneous operations of ILS and MLS during the transition period.

E. Reliability

The MLS signals are generally less sensitive than ILS signals to the effects of snow, vegetation, terrain, structures, and taxiing aircraft. This allows the reliability of this system to approach 100 percent.

F. Fix Rate

Elevation angle is transmitted at 39 samples per second, azimuth angle at 13 samples per second, and back azimuth angle at 6.5 samples per second. Usually the airborne receiver averages several data samples to provide fixes of 3 to 6 samples per second. A high rate azimuth angle function of 39 samples per second is available and is normally used where there is no need for flare elevation data.

G. Fix Dimensions

This system provides signals in all three dimensions and can provide time if aircraft are suitably equipped.

H. System Capacity

DME signals of this system are capacity limited; the system limits are approached when 110 aircraft are handled.

I. Ambiguity

No ambiguity is possible for the azimuth or elevation signals. Only a very small probability for ambiguity exists for the range signals and then only for multipath caused by moving reflectors.

J. Integrity

MLS integrity is provided by an integral monitor. The monitor shuts down the MLS within one second of an out-of-tolerance condition.

A.2.6 Transit

Transit is a space-based radiodetermination system consisting of satellites in approximately 600 nm polar orbits. The phasing of the satellites is deliberately staggered to minimize time between fixes for users. In addition, Transit has four ground-based monitors. The monitor stations track each satellite while in view and provide the tracking information necessary to update satellite orbital parameters every 12 hours.

A. Signal Characteristics

The satellites broadcast ephemeris information continuously on 150 and 400 MHz. One frequency is required to determine a position. However, by using the two frequencies, higher accuracy can be attained. A receiver measures successive Doppler, or apparent frequency shifts of the signal, as the satellite approaches or passes the user. The receiver then calculates the geographic position of the user based on knowledge of the satellite position that is transmitted from the satellite every two minutes, and knowledge of the doppler shift of the satellite signal. The characteristics of Transit are summarized in Table A-8.

B. Accuracy

Predictable positioning accuracy is 500 meters for a single frequency receiver and 25 meters for a dual frequency receiver. Repeatable positioning accuracy is 50 meters for a single frequency and 15 meters for a dual frequency receiver. Relative positioning accuracy of less than 10 meters has been measured through translocation techniques. Navigational accuracy is heavily dependent upon the accuracy to which vessel course, speed, and time are known. A one knot velocity input error can cause up to 0.2 nm fix error.

C. Availability

Availability is better than 99 percent when a Transit satellite is in view. It depends on user latitude, antenna mask angle, user maneuvers during a satellite pass, the number of operational satellites and satellite configuration.

Table A-8. Transit System Characteristics (Signal-In-Space)

ACCURACY* (Meters-2 Sigma)									
PREDICTABLE	REPEATABLE	RELATIVE	AVAILABILITY	COVERAGE	RELIABILITY	FIX RATE**	FIX DIMENSION	SYSTEM CAPACITY	AMBIGUITY POTENTIAL
Dual frequency 25m	15m	Under 10m with translocation techniques	99% when satellite is in view	Worldwide noncontinuous	99%	Every 30 seconds	2D	Unlimited	None
Single frequency 500m	50m								

* *Position accuracy is highly dependent on the user's knowledge of his velocity.*

** *Maximum satellite waiting time varies with latitude. (30 seconds at 80º, 110 minutes at equator)*

SYSTEM DESCRIPTION: Transit nominally consists of four operational satellites in polar orbits. The satellites broadcast information on 150 and 400 Mhz. A receiver measures the apparent frequency shift of the signals (Doppler) as the satellite approaches and passes the user. The receiver then calculates the geographic position of the user, based on satellite position knowledge and corrections received from the transmitted signal.

D. Coverage

Coverage is worldwide but not continuous due to the relatively low altitude of the Transit satellites and the precession of satellite orbits.

E. Reliability

The reliability of the Transit satellites is greater than 99 percent.

F. Fix Rate

Fix rate varies with latitude, theoretically from an average of 110 minutes at the equator to an average of 30 minutes at 80 degrees. Presently, due to non-uniform orbital precession, the Transit satellites are no longer in evenly spaced orbits. Consequently, a user can occasionally expect a period greater than 6 hours between fixes. This condition exists for less than 5 percent of system availability.

G. Fix Dimensions

Transit satellites provide a two-dimensional fix.

H. System Capacity

Transit satellites have unlimited capacity.

I. Ambiguity

There is no ambiguity.

J. Integrity

Transit satellite signals are monitored by the Naval Astronautics Group (NAG) at Point Mugu, California, which serves as the satellite constellation ground control facility. Whenever a satellite-transmitted signal is out-of-tolerance or otherwise unsuitable for use, NAG will issue a “SPATRAK” alerting message to all known U.S. Navy Transit users, with an information copy to DMA. DMA then ensures that the alert is entered into the Notice to Mariners system for distribution to civil users. The same procedure is used for scheduled test or preventative maintenance periods on selected satellites. Transit receivers do not possess inherent signal integrity monitoring capabilities, other than the ability to recognize and reject the scrambled signal format broadcast by selected satellites during certain NAG-implemented system tests.

A.2.7 Aeronautical Radiobeacons

Radiobeacons are nondirectional radio transmitting stations which operate in the low- and medium-frequency bands to provide ground wave signals to a receiver. A radio direction finder (RDF) is used to measure the bearing of the transmitter with respect to an aircraft or vessel.

Presently, there are 1,575 low- and medium-frequency aeronautical nondirectional beacons (NDBs). These are distributed as follows: FAA-operated Federal facilities: 728; non-Federally owned facilities: 847. Little change in the navigational status of the civil facilities is expected before the year 2000.

A. Signal Characteristics

Aeronautical NDBs operate in the 190 to 415 kHz and 510 to 535 kHz bands. Their transmissions include a coded continuous-wave (CCW) or modulated continuous-wave (MCW) signal to identify the station. The CCW signal is generated by modulating a single carrier with either a 400 Hz or a 1,020 Hz tone for Morse code identification. The MCW signal is generated by spacing two carriers either 400 Hz or 1,020 Hz apart and keying the upper carrier to give the Morse code identification. The characteristics of aeronautical NDBs are summzarized in Table A-9.

B. Accuracy

Positional accuracy derived from the bearing information is a function of geometry of the LOPs, the accuracy of compass heading, measurement accuracy, distance from the transmitter, stability of the signal, time of day, nature of the terrain between beacon and craft, and noise. In practice, bearing accuracy is on the order of $\pm$3 to $\pm$10 degrees. Achievement of $\pm$3 degree accuracy requires that the RDF be calibrated before it is used for navigation by comparing radio bearings to accurate bearings obtained visually on the transmitting antenna. Since most direction finder receivers will tune to a number of radio frequency bands, transmissions from sources of known location, such as AM broadcast stations, are also used to obtain bearings, generally with less accuracy than obtained from radiobeacon stations. For FAA flight inspection, NDB system accuracy is stated in terms of permissible needle swing: $\pm$5 degrees on approaches and $\pm$10 degrees in the en route area.

C. Availability

Availability of aeronautical NDBs is in excess of 99 percent.

D. Coverage

Extensive NDB coverage is provided by 1,575 ground stations, of which the FAA operates 728.

Table A-9. Radiobeacon System Characteristics (Signal-In-Space)

ACCURACY (2 Sigma)									
PREDICTABLE	REPEATABLE	RELATIVE	AVAILABILITY	COVERAGE	RELIABILITY	FIX RATE	FIX DIMENSION	SYSTEM CAPACITY	AMBIGUITY POTENTIAL
Aeronautical ± 3-10^{o}	N/A	N/A	99%	Maximum service volume - 75nm	99%	Continuous	One LOP per beacon	Unlimited	Potential is high for reciprocal bearing without sense antenna
Marine $\pm 3^{o}$	N/A	N/A	99%	Out to 50nm or 100 fathom curve					

SYSTEM DESCRIPTION: Aircraft nondirectional beacons are used to supplement VOR-DME for transition from en route to airport precision approach facilities and as a nonprecision approach aid at many airports. Only low frequency beacons are considered in the FRP since there is little common use of the VHF/UHF beacons. Marine radiobeacons are used as homing beacons to identify the entrance to harbors. Selected marine beacons carry differential GPS data.

E. Reliability

Reliability is in excess of 99 percent.

F. Fix Rate

The fix rate is a function of whether the beacon is continuous or sequenced. In general, at least one line of position, or relative bearing, is provided continuously. If sequenced, fixing a position may require up to six minutes, depending on the LOPs selected. The modernization effort will convert each radiobeacon to continuous service which will improve the fix rate.

G. Fix Dimensions

In general, one LOP is available from a single radiobeacon. If within one range of two or more beacons, a fix may be obtained.

H. System Capacity

An unlimited number of receivers may be used simultaneously.

I. Ambiguity

The only ambiguity which exists in the radiobeacon system is one of reciprocal bearing provided by some receiving equipment which does not employ a sense antenna to resolve direction.

J. Integrity

A radiobeacon is an omnidirectional navigational aid. For aviation radiobeacons, out-of-tolerance conditions are limited to output power reduction below operating minimums and loss of the transmitted station identifying tone. The radiobeacons used for nonprecision approaches are monitored and will shut down within 15 seconds of an out-of-tolerance condition.

A.2.8 Maritime Radiobeacons

Radiobeacons are nondirectional radio transmitting stations which operate in the low- and medium-frequency bands to provide ground wave signals to a receiver. An RDF is used to measure the bearing of the transmitter with respect to an aircraft or vessel.

There are approximately 85 USCG-operated marine radiobeacons. Some maritime radiobeacons will be modified to carry differential GPS correction signals. These maritime radiobeacons will remain part of the radionavigation systems mix into the next century. The remaining marine radiobeacons are expected to be phased out by the year 2000.

A. Signal Characteristics

Marine radiobeacons operate in the 285 to 325 kHz band. The signal characteristics for marine radiobeacons are summarized in Table A-9. Radiobeacons used for DGPS will be modulated with minimum shift keying (MSK) modulation to broadcast DGPS corrections (see section A.2.10.1). In addition, radiobeacons may be operated in a single carrier mode resulting in the elimination of the Morse code identifier. A decision on the single carrier operation will be made by 1996.

B. Accuracy

Positional accuracy derived from the bearing information is a function of geometry of the LOPs, the accuracy of compass heading, measurement accuracy, distance from the transmitter, stability of the signal, time of day, nature of the terrain between beacon and craft, and noise. In practice, bearing accuracy is on the order of ± 3 to ± 10 degrees. Achievement of ± 3 degree accuracy requires that the RDF be calibrated before it is used for navigation by comparing radio bearings to accurate bearings obtained visually on the transmitting antenna. Since most direction finder receivers will tune to a number of radio frequency bands, transmissions from sources of known location, such as AM broadcast stations, are also used to obtain bearings, generally with less accuracy than obtained from radiobeacon stations.

C. Availability

Availability of marine radiobeacons is in excess of 99 percent.

D. Coverage

The coverage of marine radiobeacons is changing as radiobeacons with little to no identified users are discontinued.

E. Reliability

Reliability is in excess of 99 percent. Radiobeacons used for DGPS broadcasts will have reliability in excess of 99.7 percent.

F. Fix Rate

The fix rate is provided continuously.

G. Fix Dimensions

In general, one LOP is available from a single radiobeacon. If within range of two or more beacons, a fix may be obtained.

H. System Capacity

An unlimited number of receivers may be used simultaneously.

I. Ambiguity

The only ambiguity which exists in the radiobeacon system is one of reciprocal bearing provided by some receiving equipment which does not employ a sense antenna to resolve direction.

J. Integrity

A radiobeacon is an omnidirectional navigational aid. Marine radiobeacons are monitored either continuously or periodically, depending on equipment configuration. Radiobeacons broadcasting operational DGPS corrections are monitored continuously. Notification of outages is provided by a broadcast Notice to Mariners. Outages of long duration are announced in both the Local Notice to Mariners and the Notice to Mariners.

A.2.9 GPS

GPS is a space-based radionavigation system which is managed for the Government of the United States by the U.S. Air Force, the system operator. GPS was originally developed as a military force enhancement system and will continue to play this role; however, GPS also has significant potential to benefit the civil community in an increasingly large number and variety of applications. In an effort to make GPS service available to the greatest number of users while ensuring that national security interests of the United States are protected, two GPS services are provided. The Precise Positioning Service (PPS) provides full system accuracy primarily to U.S. and allied military users. The Standard Positioning Service (SPS) is designed to provide accurate positioning capability for civil users throughout the world. The GPS has three major segments: space, control, and user.

The GPS Space Segment is composed of 24 satellites in six orbital planes. The satellites operate in circular 20,200 km (10,900 nm) orbits at an inclination angle of 55 degrees and with a 12-hour period. The spacing of satellites in orbit are arranged so that a minimum of 5 satellites are in view to users worldwide, with a Position of Dilution (PDOP) of six or less.

The GPS Control Segment has five monitor stations and three ground antennas with uplink capabilities. The monitor stations use a GPS receiver to passively track all satellites in view and accumulate ranging data from the satellite signals. The information from the monitor stations is processed at the Master Control Station (MCS) to determine satellite clock and orbit states and to update the navigation message of each satellite. This updated information is transmitted to the satellites via the ground antennas, which are also used for transmitting and receiving health and control information.

The GPS User Segment consists of a variety of configurations and integration architectures that include an antenna and receiver-processor to receive and compute navigation solutions to provide positioning, velocity, and precise timing to the user.

A. Signal Characteristics

Each satellite transmits three separate spectrum signals on two L-band frequencies, L1 (1575.42 MHz) and L2 (1227.6 MHz). L1 carries a Precise P (Y) Pseudo-Random Noise (PRN) code and a Coarse/Acquisition (C/A) PRN code; L2 carries the P(Y) PRN code. (The Precise code is denoted as P(Y) to identify that this PRN code can be operated in either a clear unencrypted "P" or an encrypted "Y" code configuration.) Both PRN codes carried on the L1 and L2 frequencies are phase-synchronized to the satellite clock and modulated (using modulo two addition) with a common 50 Hz navigation data message.

In order to support civil GPS applications, the SPS user is guaranteed system access through the use of the L1 C/A signal while the P(Y) code on L1 and L2 is reserved for PPS requirements. The SPS signal received by the user is a spread spectrum signal centered on L1 with a 2.046 MHz bandwidth. Minimum SPS received power is specified as -160.0 dBW. The navigation data contained in the signal is composed of satellite clock and ephemeris data for the transmitting satellite plus GPS constellation almanac data, GPS to UTC time offset information, and ionospheric propagation delay correction parameters for single frequency users. The entire navigation message repeats every 12.5 minutes. Within this 12.5-minute repeat cycle, satellite clock and ephemeris data for the transmitting satellite is sent 25 separate times so it repeats every 30 seconds. As long as a satellite indicates a healthy status, a receiver can continue to operate using this data for the validity period of the data (up to 4 or 6 hours). Normally however, the receiver will update this data whenever the satellite and ephemeris information is updated - nominally once every 2 hours.

The concept of GPS position determination is based on the intersection of four separate vectors each with a known origin and a known magnitude. Vector origins for each satellite are computed based on satellite ephemeris. Vector magnitudes are calculated based on signal propagation time delay as measured from the transmitting satellite's PRN code phase delay. Given that the satellite signal travels at nearly the speed of light and taking into account delays and adjustment factors such as ionospheric propagation delays and earth rotation factors, the receiver performs ranging measurements between the individual satellite and the user by dividing the satellite signal propagation time by the speed of light.

These measurements are combined to yield system time and the user's three-dimensional position with respect to World Geodetic Systems, 1984 (WGS-84) Earth Centered - Earth Fixed (ECEF) coordinates. A user's velocity can thus be computed by propagating the user's position with respect to time. Standard coordinate transformations are then performed within the receiver to provide user position and velocity in local coordinates (e.g., North American Datum 1987 latitude, longitude, and altitude coordinates).

A stand-alone GPS receiver requires four simultaneous measurements from four satellites to determine position in three dimensions and time. The receiver uses the four simultaneous measurements to yield four linearized mathematical equations with four unknowns from which the four unknowns can be solved (e.g., latitude, longitude, altitude, and time). If the user needs only two-dimensional positioning and time determination, only three simultaneous measurements are required for three equations and three unknowns (latitude, longitude, and time). If the user needs only time determination, only one satellite measurement is required for one equation and one unknown (time). The characteristics of GPS are summarized in Table A-10.

B. Accuracy

GPS provides two services for position determination, SPS and PPS. Accuracy of a GPS fix varies with the capability of the user equipment.

1. Standard Positioning Service (SPS)

SPS is the standard specified level of positioning and timing accuracy that is available, without restrictions, to any user on a continuous worldwide basis. The accuracy of this service will be established by the DOD and DOT based on U.S. security interests. SPS provides a predictable positioning accuracy of 100 meters (95 percent) horizontally and 156 meters (95 percent) vertically and time transfer accuracy to UTC within 340 nanoseconds (95 percent).

2. Precise Positioning Service (PPS)

PPS is the most accurate direct positioning, velocity, and timing information continuously available, worldwide, from the basic GPS. This service is limited to users specifically authorized by the U.S. P(Y) code capable military user equipment provides a predictable positioning accuracy of at least 22 meters (95 percent) horizontally and 27.7 meters vertically and time transfer accuracy to UTC within 200 nanoseconds (95 percent).

C. Availability

Provided there is coverage as defined below, SPS will be available at least 99.85 percent of the time.

D. Coverage

The probability that 4 or more GPS satellites over any 24-hour interval with a PDOP of 6 or less, with at least a 5^{o} mask angle is at least 99.9 percent (global average).

Table A-10. GPS Characteristics (Signal-In-Space)

SPS ACCURACY (METERS) - 95%			SERVICE		SERVICE	FIX	FIX	SYSTEM	AMBIGUITY
PREDICTABLE	REPEATABLE	RELATIVE*	AVAILABILITY	COVERAGE	RELIABILITY	RATE	DIMENSION	CAPACITY	POTENTIAL
Horz - 100 Vert - 156 Time - 340ns	Horz - 141 Vert - 221	Horz - 1.0 Vert - 1.5	99.16%	99.90% (PDOP $\leq$ 6)	99.79%	Essentially continuous	3D + Time	Unlimited	None

* *Receivers using the same satellites with position solutions computed at approximately the same time.*

SYSTEM DESCRIPTION: GPS is a space-based radio positioning navigation system that provides three-dimensional position and time information to suitably equipped users anywhere on or near the surface of the Earth. The space segment consists of 24 satellites in 6 orbital planes of 12-hour periods. Each satellite transmits navigation data and time signals on 1575.42 and 1227.6 Mhz.

E. Reliability

Conditioned on coverage and service availability, the probability that the horizontal positioning error will not exceed 500 meters at any time is at least 99.7 percent.

F. Fix Rate

The fix rate is essentially continuous. Actual time to a first fix depends on user equipment capability and initialization with current satellite almanac data.

G. Fix Dimensions

GPS provides three-dimensional positioning when four or more satellites are available and two-dimensional positioning when only three satellites are available.

H. System Capacity

The capacity is unlimited.

I. Ambiguity

There is no ambiguity.

J. Integrity

The basic GPS must be augmented to meet current civil aviation and marine integrity requirements. Receiver Autonomous Integrity Monitoring (RAIM), a receiver software program, and DGPS are two methods of satisfying integrity requirements.

DOD GPS receivers use the information contained in the navigation and health messages, as well as self-contained satellite geometry algorithms and internal navigation solution convergence monitors, to compute an estimated figure of merit. This number is continuously displayed to the operator, indicating the estimated overall confidence level of the position information.

Both DOT and DOD have recognized the requirement for additional integrity for aviation and all other users of GPS. The development of integrity capabilities to meet flight safety requirements is underway.

A.2.10 Augmentations to GPS

GPS may exhibit variances from a predicted grid established for navigation, charting, or derivation of guidance information. This variance may be caused by propagation anomalies, errors in geodesy, accidental perturbations of signal timing, or other factors.

DGPS enhances GPS through the use of differential corrections to the basic satellite measurements. DGPS is based upon accurate knowledge of the geographic location of one or more reference stations, which is used to compute corrections to GPS parameters, error sources, and/or resultant positions. These differential corrections are then transmitted to GPS users, who apply the corrections to their received GPS signals or computed position. For a civil user of SPS, differential corrections can improve navigational accuracy from 100 meters (2 drms) to better than 7 meters (2 drms). A DGPS reference station is fixed at a geodetically surveyed position. From this position, the reference station typically tracks all satellites in view, downloads ephemeris data from them, and computes corrections based on its measurements and geodetic position. These corrections are then broadcast to GPS users to improve their navigation solution. There are two well-developed methods of handling this:

- Computing and transmitting a position correction in x-y-z coordinates, which is then applied to the user's GPS solution for a more accurate position.
- Computing pseudorange corrections for each satellite, which are then broadcast to the user and applied to the user's pseudorange measurements before the GPS position is calculated by the receiver, resulting in a highly accurate navigation solution.

The first method, in which the correction terms for the x-y-z coordinates are broadcast, requires less data in the broadcast than the second method, but the validity of those correction terms decreases rapidly as the distance from the reference station to the user increases. Both the reference station and the user receiver must use the same set of satellites for the corrections to be valid. This condition is often difficult to achieve, and limits operational flexibility.

Using the second method, an all-in-view receiver at the reference site receives signals from all visible satellites and measures the pseudorange to each. Since the satellite signal contains information on the precise satellite orbits and the reference receiver knows its position, the true range to each satellite can be calculated. By comparing the calculated range and the measured pseudorange, a correction term can be determined for each satellite. The corrections are broadcast and applied to the satellite measurements at each user's location. This method provides the best navigation solution for the user and is the preferred method. It is the method being employed by the U.S. Coast Guard DGPS Service.

An elaboration of the second method is being incorporated in the FAA's WAAS for GPS. In this system, a network of GPS reference/measurement stations at surveyed locations collects dual-frequency measurements of GPS pseudorange and pseudorange rate for all spacecraft in view, along with local meteorological conditions. These data can be processed to yield highly accurate ephemeris, ionospheric and tropospheric calibration maps, and DGPS corrections for the broadcast spacecraft ephemeris and clock offsets (including the effects of Selective Availability (SA). In the WAAS, these GPS corrections and system integrity messages will be relayed to civil users via a dedicated package on geostationary satellites. This relay technique will also support the delivery of an additional ranging signal, thereby increasing overall navigation system availability.

A.2.10.1 Maritime DGPS

Figure A-2 shows the USCG system concept using pseudorange corrections. The reference station's and the mariner's pseudorange calculations are strongly correlated. Pseudorange corrections computed by the reference station, when transmitted to the mariner in a timely manner, can be directly applied to the mariner's pseudorange computation to dramatically increase the resultant accuracy of the pseudorange measurement before it is applied within the mariner's navigation solution. The USCG DGPS prototype sites are achieving accuracies on the order of 1 meter.

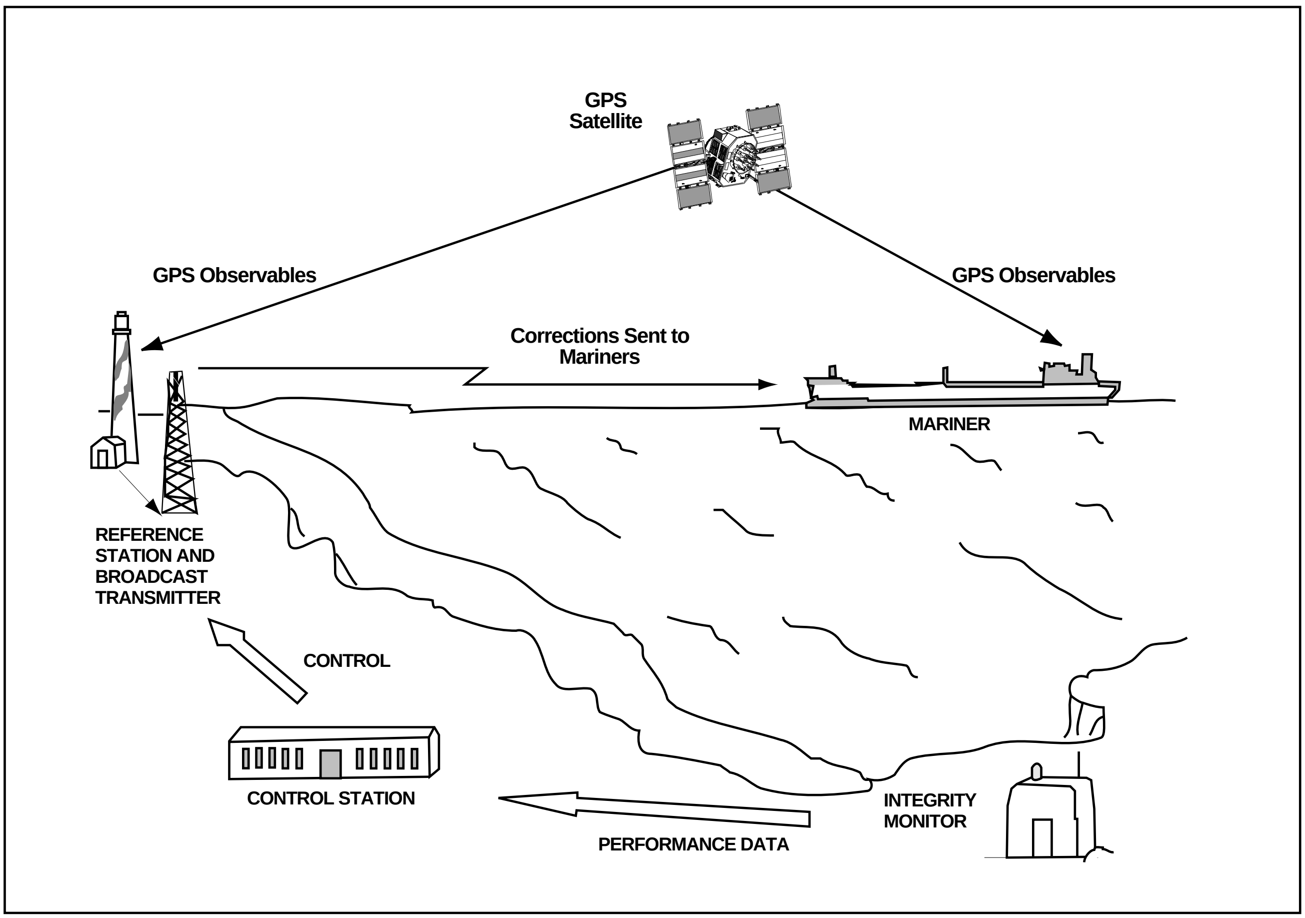

Figure A-2. USCG DGPS System Concept

A. Signal Characteristics

Maritime radiobeacons are being modified to accept MSK modulation. Real-time differential GPS corrections are input in the Radio Technical Commission for Maritime Services Special Committee 104 (RTCM SC-104) format and broadcast to all users capable of receiving the signals. The USCG does not plan to use data encryption. Radiobeacons were chosen because of existing infrastructure, compatibility with the useful range of DGPS corrections, international radio conventions, international acceptance, commercial availability of equipment, and highly successful field tests.

The data rate of DGPS transmissions will be 100 bps and 200 bps in selected waterways with more stringent VTS requirements. Prior to full implementation of DGPS, a decision may be made to use a 200 bps data rate at all DGPS broadcast sites.

The USCG's DGPS system will broadcast corrections to the user in the RTCM SC-104 format. The RTCM has defined data messages and an interface between the DGPS receiver and the data link receiver. The USCG DGPS Broadcast Standard (Commandant Instruction M16577.1) should be consulted for detailed information on the DGPS broadcasts. A description of some of the message types is contained below:

- **Type 1 <u>Differential GPS Corrections</u>**. This message contains the pseudorange corrections (PRC) and range-rate corrections (RRC) for all satellites in view of the reference station. When the USCG's DGPS service is fully implemented, the use of Type 1 message will be replaced by the Type 9 message.
- **Type 2 <u>Delta Differential GPS Corrections</u>.** Type 2 messages will not be used by the USCG DGPS Service. Continuous tracking receivers make the need for Type 2 messages obsolete and use of the message would only increase the latency of the broadcast. For each new issue of data (IOD) , there will be a 90 second delay before the broadcast of pseudorange corrections are computed with the new IOD.
- **Type 3 <u>Reference Station Parameters</u>.** The NAD 83 coordinates of the reference station with a resolution of 0.01 meter are found here. This message will nominally be broadcast twice per hour. User derived atmospheric corrections may be added through use of this message type.
- **Type 6 <u>Null Frame</u>**. This message is used to maintain data link synchronization in the event there are no other RTCM messages to transmit. In the operational GPS scenario, transmission of this message will be rare indeed.

- **Type 7 <u>Radiobeacon Almanac</u>.** This message provides location, frequency, service range and health information for adjacent broadcast transmitters as well as for the radiobeacon from which the message is broadcast. It can be used to acquire the next transmitter when in transit down the coast. This message will nominally be sent every 10 minutes.

- **Type 9 <u>High Rate Differential GPS Corrections</u>**. Due to the advantages of greater impulse noise immunity, lower latency, less susceptibility to SA on one or more satellites, and a more timely alarm capability, the Type 9 message has been selected over the Type 1 message. Recent tests have demonstrated the substantial advantage gained through this use of the Type 9 message. PRC and RRC are broadcast for up to nine satellites which are above a 7.5 degree mask angle. The message indicates the nominal time (shown below as t_o) for which this data was valid. The user computes the current differential correction as follows:

$$PRC(t) = PRC(t_o) + RRC \cdot (t-t_o),$$

  where $PRC(t_o)$ is the PRC value in the PRC message. The user then applies the PRC by adding it to their pseudorange measurement. The RRC is included in an attempt to extend the life of the PRC, as the RRC is a “rate” term which is used to propagate PRCs in time. The Type 9 messages will contain the corrections for up to three satellites for each message. Also, unlike the Type 1 message, Type 9 messages can be used in accordance with the RTCM and IALA standards. The information contained before the first word with an uncorrectable error can be used.

- **Type 15 <u>Atmospheric Parameters</u>.** (To be developed.) The USCG plans to work with the National Geodetic Survey and the U.S. Army Corps of Engineers in developing this message to extend the high level of accuracy provided by the Reference Station further out into the coverage area. The use of a dual frequency Reference Station to generate this message will be explored - this particular message will most likely be of use only to the dual frequency user.

- **Type 16 <u>Special Message</u>.** This is an ASCII message up to 90 characters long. It can be sent by service providers to broadcast warning information, such as scheduled outages. User equipment should have the ability to display this information to the navigator, with audible warning of receipt.

B. Accuracy

The accuracy of the USCG's DGPS service is expected to be better than 10 meters (2 drms) in all approaches to major U.S. harbors. Prototype operations are now achieving accuracies on the order of 1 meter.

C. Availability

Availability will be 99.9 percent in selected waterways with more stringent VTS requirements and at least 99.7 percent in other parts of the coverage area.

D. Coverage

Figure A-3 shows the expected coverage of the USCG's maritime DGPS system.

E. Reliability

The number of outages per site will be less than 500 in one million hours of operation with a time to alarm of less than five seconds.

F. Fix Rate

The DGPS reference station computes corrections at least once per second. Due to the transmission time, users will receive updated corrections on an average of every five seconds for beacons transmitting at 100 bps and every 2.5 seconds for beacons transmitting at 200 bps.

G. Fix Dimensions

Maritime differential GPS provides three-dimensional positioning and velocity fixes.

H. System Capacity

Unlimited.

I. Ambiguity

None.

J. Integrity

DGPS system integrity is provided through an on-site integrity monitor and 24-hour operations at a DGPS control center. Users will be notified of an out-of-tolerance condition within five seconds.

In addition to providing a highly accurate navigational signal, DGPS also provides a continuous integrity check on satellite health. System integrity is a real concern with GPS. With the design of the ground segment of GPS, a satellite can be transmitting an unhealthy signal for 2 to 6 hours before it can be detected and corrected by the

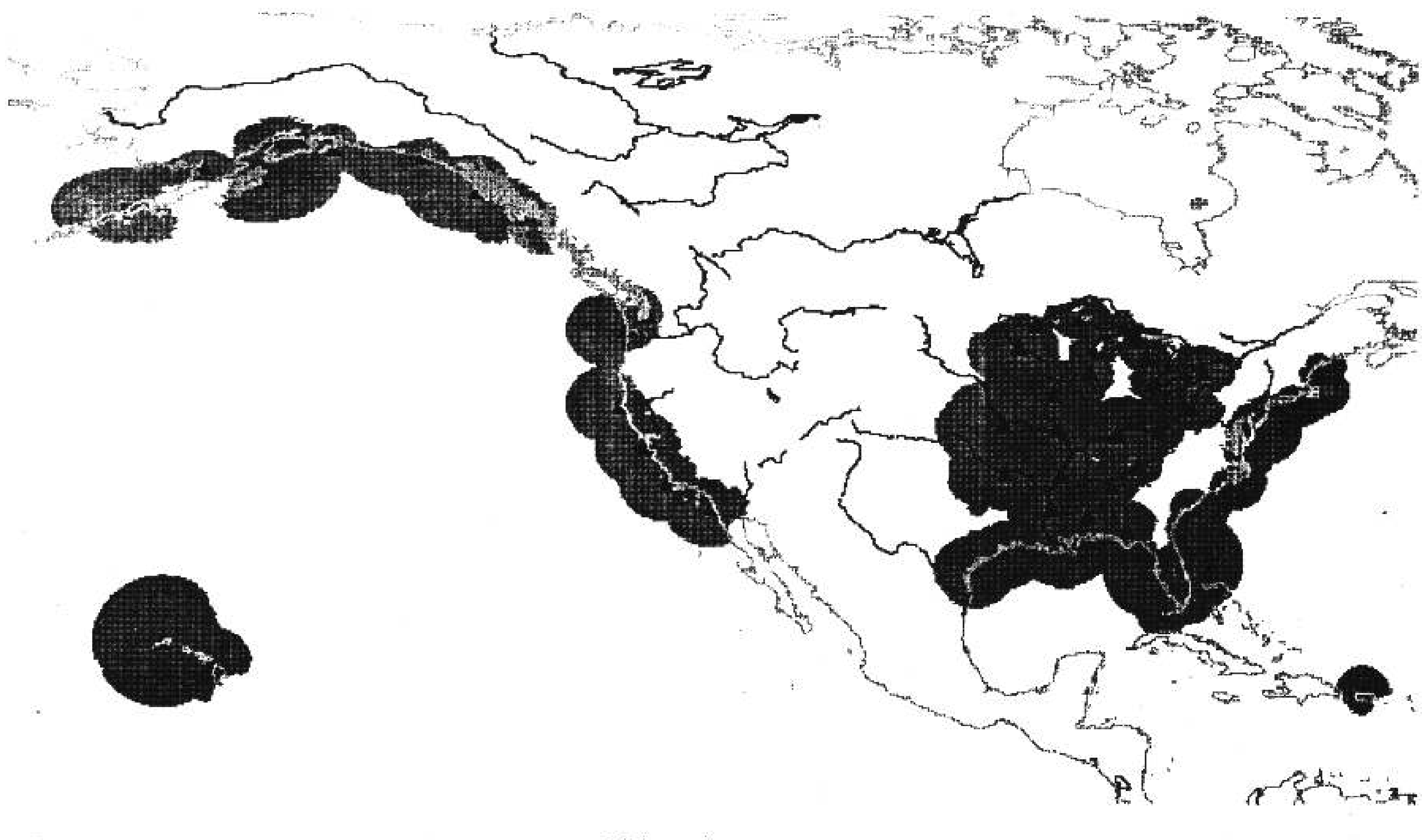

Figure A-3. Proposed Conus, Alaska and Hawaii Maritime DGPS Coverage

Master Control Station or before users can be warned not to use the signal. But with the continuous, real-time messages generated by DGPS, unhealthy satellites can still be used, or the navigator's receiver is directed not to use a particular satellite. This can eliminate the danger of the navigator relying on an erroneous signal.

A.2.10.2 Aeronautical GPS Wide Area Augmentation System (WAAS)

The WAAS will be a safety-critical system consisting of the equipment and software which augments the DOD-provided GPS Standard Positioning Service (see Figure A-4). It will provide a signal in space to WAAS users with the specific goal of supporting aviation navigation for the en route through Category I precision approach phases of flight. The signal in space will provide three services: (1) integrity data on GPS and GEO satellites, (2) wide area differential corrections for GPS satellites, and (3) an additional ranging capability.

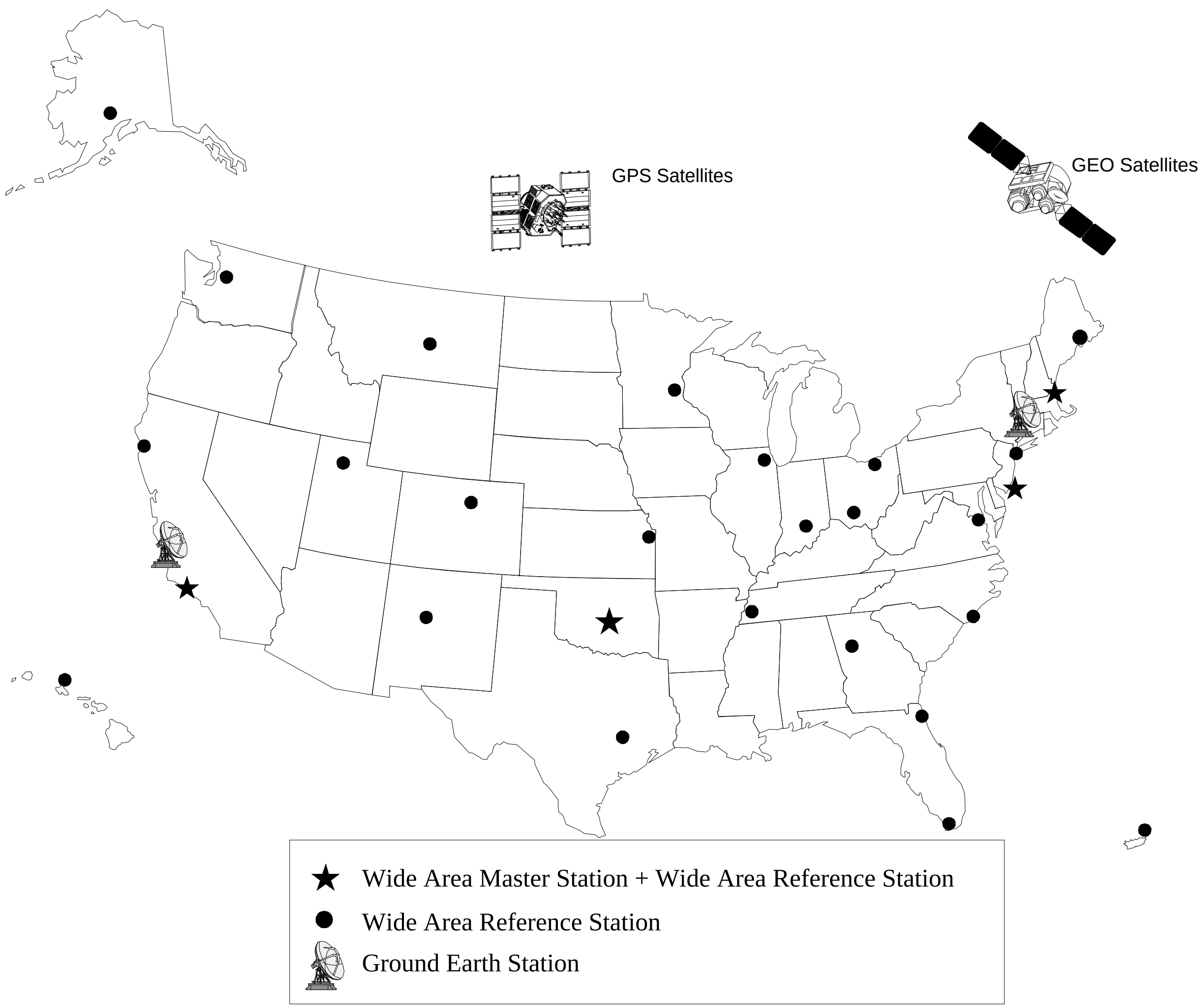

Figure A-4. WAAS Architecture

The GPS satellites' data is to be received and processed at widely dispersed sites, referred to as Wide-area Reference Stations (WRS). These data are forwarded to data processing sites, referred to as Wide-area Master Stations (WMS), which process the data to determine the integrity, differential corrections, residual errors, and ionospheric information for each monitored satellite and generate GEO satellite navigation parameters. This information is to be sent to a Ground Earth Station (GES) and uplinked along with the GEO navigation message to GEO satellites. These GEO satellites will then downlink this data on the GPS Link I (LI) frequency with a modulation similar to that used by GPS.

In addition to providing GPS integrity, the WAAS will verify its own integrity and take any necessary action to ensure that the system meets the WAAS performance requirements. The WAAS also has a system operations and maintenance function that provides information to FAA Airway Facilities NAS personnel.

The WAAS user receiver will process: (1) the integrity data to ensure that the satellites being used are providing in-tolerance navigation data, (2) the differential correction and ionospheric information data to improve the accuracy of the user's position solution, and (3) the ranging data from one or more of the GEO satellites for position determination. The WAAS user receivers are not considered part of the WAAS.

A. Signal Characteristics

The WAAS will collect raw GPS obervable data through the GPS LI-C/A pseudorange data, the GPS LI/Link 2 (L2) code differential data (without knowledge of the Y-code), and the satellite navigation data from all GPS satellites that support the navigation service.

WAAS ground equipment will develop messages on ranging signals and signal quality parameters of the GPS and GEO satellites. GEO satellites will broadcast the WAAS messages to the users and provide ranging sources. The signals broadcast via the WAAS GEOs to the WAAS users are designed to require minimal standard GPS receiver hardware modifications. The GPS frequency and GPS-type modulation, including a C/A PRN code, will be used. In addition, the code phase timing will be synchronized to GPS time to provide a ranging capability.

B. Accuracy

Accuracies for the WAAS are currently based on aviation requirements. For the en route through nonprecision approach phases of flight, a horizontal accuracy of 100 meters 95 percent of the time is guaranteed with the requisite availability and integrity levels to support operations in the NAS. For the Category I precision approach phase of flight, horizontal and vertical accuracies are guaranteed at 7.6 meters 95 percent of the time.

C. Availability

The WAAS availability for the en route through nonprecision approach phases of flight is at least 0.99999. For the precision approach phase of flight, the availability is at least 0.999.

D. Coverage

The WAAS full service volume is defined from the surface up to 100,000 feet for the airspace of the 48 contiguous states, Hawaii, Puerto Rico, and Alaska (except for the Alaskan peninsula west of longitude 160 degrees West or outside of the GEO satellite broadcast area).

E. Reliability

The WAAS will provide sufficient reliability and redundancy to meet the overall NAS requirements with no single point of failure. The overall reliability of the WAAS will approach 100 percent.

F. Fix Rate

This system provides a virtually continuous position update.

G. Fix Dimensions

The WAAS provides three-dimensional position fixing and highly-accurate timing information.

H. System Capacity

The user capacity is unlimited.

I. Ambiguity

The system provides no ambiguity of position fixing information.

J. Integrity

Integrity augmentation of the GPS SPS by the WAAS is a required capability that is both an operational characteristic and a technical characteristic. The required system performance levels for the integrity augmentation are the levels necessary so that GPS/WAAS can be used for all phases of flight.

Integrity for the WAAS is specified by three parameters: probability of hazardously misleading information (PHMI), time to alarm, and the alarm limit. For the en route through nonprecision approach phases of flight, the performance values are:

PHMI	10^{-7} per hour
Time to Alarm	8 seconds
Alarm Limit	Protection limits specified for each phase of flight

For the precision approach phase of flight, integrity performance values are:

PHMI	4×10^{-8} per approach
Time to Alarm	5.2 seconds
Alarm Limit	As required to remain within the category I tunnel

A.2.11 VTS

For information on VTS system characteristics, please contact the U.S. Coast Guard (G-NVT).

A.3 GPS Information Center (GPSIC)/Navigation Information Service

The U.S. Coast Guard's GPS Information Center (GPSIC), now called the Navigation Information Service, is the operational entity of the Civil GPS Service (CGS) which provides GPS status information to civil users of GPS. Its input is based on data from the GPS Control Segment, Department of Defense, and other sources. The mission of the GPSIC is to gather, process and disseminate timely GPS status information to civil users of GPS. Specifically, the functions performed by the Navigation Information Service include the following:

- Provide the Operational Advisory Broadcast (OAB) Service.
- Answer questions by telephone or written correspondence.
- Provide information to the public on the GPSIC services available.
- Provide instruction on the access and use of the information services available.
- Maintain tutorial, instructional, and other relevant handbooks and material for distribution to users.
- Maintain records of GPS broadcast information, GPS databases or relevant data for reference purposes.
- Maintain bibliography of GPS publications.

- Maintain and augment the computer and communications equipment as required.

- Develop new user services as required.

The GPSIC is transitioning to a Navigation Information Service and provides information on the status of the USCG operated radionavigation services such as Loran-C, Omega, and the developing DGPS service as well as other navigation information.

Information on GPS and USCG-operated radionavigation systems can be obtained from the USCG's Navigation Center (NAVCEN), 7327 Telegraph Road, Alexandria, VA 22315-3998 by mail, or by telephone (703-313-5900) or fax (703-313-5920).

Table A-11 and Figure A-5 show the services through which the GPSIC provides Operational Advisory Broadcasts.

A.4 Intelligent Transportation Systems

The Intelligent Transportation Systems (ITS) program applies advanced and emerging technologies to surface transportation needs. Successful deployment of ITS services and systems will achieve improvements in safety, mobility and productivity, and reduce harmful environmental impacts, particularly those caused by traffic congestion. The ITS program has evolved from six major system areas, Advanced Traffic Management Systems (ATMS), Advanced Traveler Information Systems (ATIS), Commercial Vehicle Operations (CVO), Advanced Vehicle Control Systems (AVCS), Advanced Public Transportation Systems (APTS), and Advanced Rural Transportation Systems (ARTS) into twenty eight inter-related user services which have been defined to date as part of the national program planning process. The basic components of the ITS are shown in Figure A-6. User services are defined, not along lines of common technologies, but based upon the services or benefits that various users might receive. The services are in various stages of maturity; some are available today, but others will require significant research, development, testing, and advances in technology applications before they are ready for deployment. The user services have been grouped into "bundles," based on likely deployment scenarios. The following is a description of the user services.

Travel and Traffic Management

- **Pre-Trip Travel Information**: Travelers access a complete range of intermodal transportation information at home, work, and other major sites where trips originate. For example, timely information on transit routes, schedules, transfers and fares, and ride matching services are included. Real-time information on accidents, road construction, alternate routes, traffic speeds along given routes, parking conditions,

Table A-11. GPSIC Services

Service	Availability	Information Type	Contact Number
GPSIC Watchstander	24 hours	User Inquiries	(703) 313-5900 FAX (703) 313-5920
GPSIC Computer Bulletin Board Service	24 hours	Status Forecasts/Historic Outages NGS Data Omega/FRP Misc Information	(703) 313-5910 300-14,400 bps Sprintnet (X.25) 311020201328
GPSIC Voice Tape Recording	24 hours	Status Forecasts Historic	(703) 313-5907
WWV	Minutes 14 & 15	Status Forecasts	2.5, 5, 10, 15 and 20 MHz
WWVH	Minutes 43 & 44	Status Forecasts	2.5, 5, 10, and 15 MHz
USCG MIB	When Broadcasted	Status Forecasts	VHF Radio, Marine Band
DMA Broadcast Warnings	When Broadcasted	Status Forecasts Outages	
DMA Weekly Notice to Mariners	Published & Mailed Weekly	Status Forecasts Outages	(301) 227-3126
DMA NAVINFONET Automated Notice to Mariners System	24 hours	Status Forecasts Historic Almanacs For More Information Call	(301) 227-3351 300 Baud (301) 227-5925 1200 Baud (301) 277-4360 2400 Baud (301) 227-3296
NAVTEX Data Broadcast	When broadcasted 4 - 6 time/day	Status Forecasts Outages	518 kHz

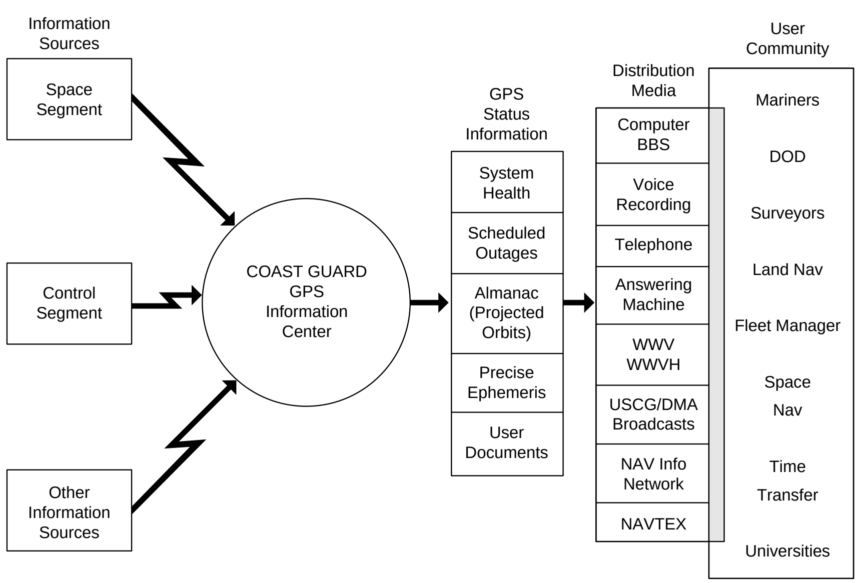

Figure A-5. GPSIC Information Flow

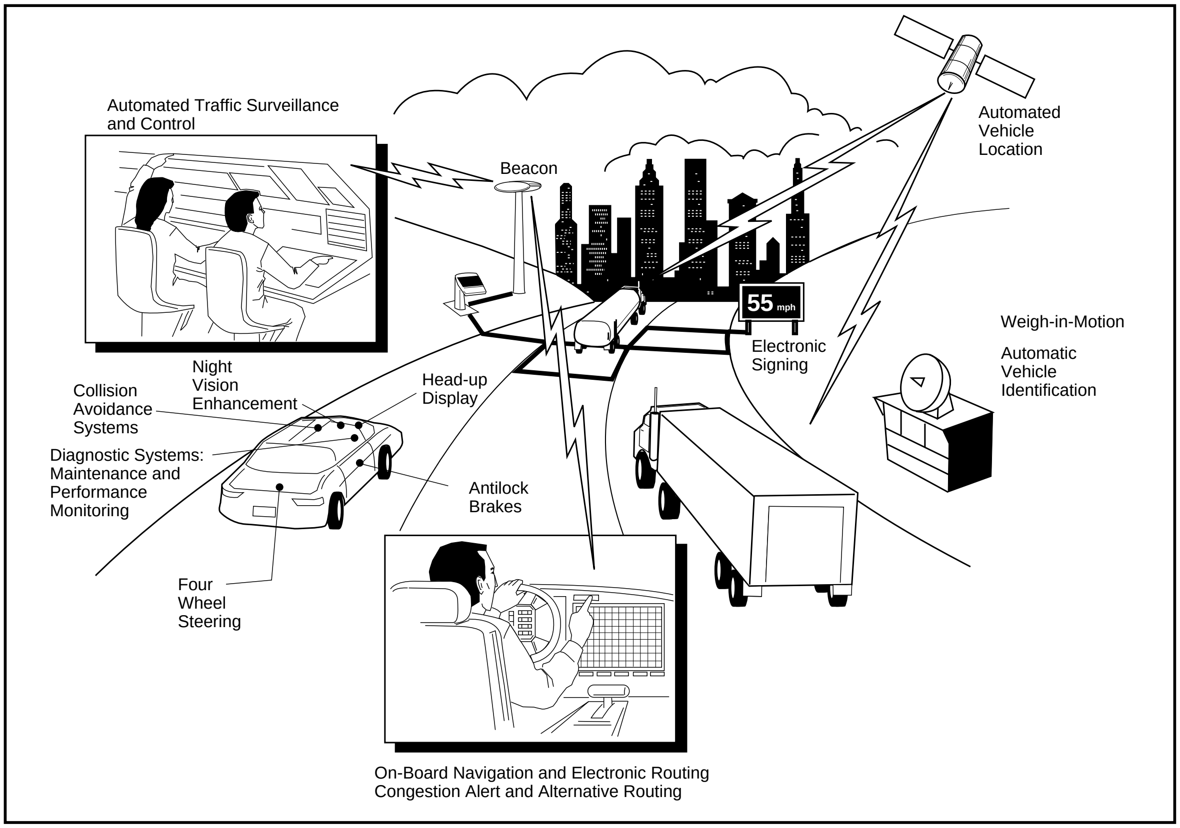

Figure A-6. Basic Components of Intelligent Transportation Systems

event schedules, and weather information complete the service. Based on this information, the traveler can select the best departure time, route and modes of travel, or decide to postpone or not to make the trip at all. Reducing congestion and improving mobility benefits all potential travelers.

- **En Route Driver Information:** Driver advisories are similar to pre-trip planning information, but are provided once travel begins. Driver advisories convey information about traffic conditions, incidents, construction, transit schedules, and weather conditions to drivers of personal, commercial and public transit vehicles. This information allows a driver to select the best route, or shift to another mode mid-trip if desired.

  In-vehicle signing, the second component of en-route driver information, would provide the same types of information found on physical road signs today, directly in the vehicle. The service could be extended to include warnings of road conditions and safe speeds for specific types of vehicles (e.g., autos, buses, large trucks), but potential users include drivers of all types of vehicles. This service might be especially useful to elderly drivers, or in rural areas with large numbers of tourists and unusual or hazardous roadway conditions.

- **Traveler Services Information**: Provides quick access to travel related services and facilities. Examples of information that might be included are the location, operating hours, and availability of food, parking, auto repair, hospitals, and police facilities. Traveler services information would be accessible in the home, office or other public locations to help plan trips, and might also be available en route. When fully deployed, this service will connect users and providers interactively, to request and provide needed information. A comprehensive, integrated service could support financial transactions like automatic billing for purchases.

- **Route Guidance**: Provides a suggested route to reach a specified destination. Early route guidance systems will be based on static information about the roadway network, transit schedules, etc. When fully deployed, route guidance systems will provide travelers with directions to their destinations based on real-time information about the transportation system. The route guidance service will consider traffic conditions, status and schedules of transit systems, and road closures in developing the best route. Directions will generally consist of simple instructions on turns or other upcoming maneuvers. Users of the service include not only drivers of all types of vehicles, but also non-vehicular travelers, such as pedestrians or bicyclists, who could get specialized route guidance from a hand-held device.

- **Ride Matching and Reservation**: Provides real-time ride matching information and reservations to users in their homes, offices or other locations, and assists transportation providers with vehicle assignments and scheduling. The service will also provide a clearinghouse for financial transactions. This will expand the market for ridesharing as an alternative to single occupant automobile travel, and will provide for enhanced alternatives for special population groups, such as the elderly or the handicapped. Convenient ride sharing is especially important to commuters.

- **Incident Management**: Enhances existing capabilities for detecting incidents and taking the appropriate actions in response to them. The service will help officials to quickly and accurately identify a variety of incidents, and to implement a response which minimizes the effects of these incidents on the movement of people and goods. Traffic movement adjustments over a wide area would be executed through the Traffic Control user service, while decisions at the site of the incident will be made by police agencies. In addition, the service will help officials to predict traffic or highway conditions so that they can take action in advance to prevent potential incidents or minimize their impacts. While the users of this service are primarily public officials, commercial and transit operators and the traveling public all benefit from improved incident management capabilities.

- **Travel Demand Management**: Generates and communicates management and control strategies that support the implementation of programs to (1) reduce the number of individuals who choose to drive alone, especially to work, (2) increase the use of high occupancy vehicles and transit, (3) reduce the impacts of high polluting vehicles, and (4) provide a variety of mobility options for those who wish to travel in a more efficient manner, for example in non-peak periods. The service allows employers to better accommodate the needs and lifestyles of employees by encouraging alternative work arrangements such as variable work hours, compressed work weeks, and telecommuting. Travel demand management strategies could ultimately be applied dynamically, when congestion or pollution conditions warrant. For example, disincentives such as increased tolls and parking fees could be applied during pollution alerts or when major incidents occur, while transit fares would be lowered to accommodate the increased number of travelers changing modes from driving alone. Such strategies will reduce the negative impacts of traffic congestion on the environment and overall quality of life.

- **Traffic Control**: Integrates and adaptively controls the freeway and surface street systems to improve the flow of traffic, give preference to transit and other high occupancy vehicles, and minimize congestion while maximizing the movement of people and goods. Through appropriate traffic controls, the service will also promote the safety of non-vehicular traveler, such as pedestrians and bicyclists. This service gathers data from the transportation system, fuses it into usable information, and uses it to determine the optimum assignment of right-of-way to vehicles and pedestrians. The real-time traffic information collected by the Traffic Control service also provides the foundation for many other user services.

  While the actual users of the service will generally be public transportation officials, drivers of all types of vehicles, transit riders, pedestrians, bicyclists, and other travelers benefit from improved traffic flow.

Public Transportation Management

- **En Route Transit Information**: Provides the same type of information as pre-trip planning services, once public transportation travel begins. Real-time, accurate transit service information on board the vehicle helps travelers make effective transfer decisions and itinerary modifications as needed while a trip is underway.

- **Public Transportation Management**: Computer analysis of real-time vehicle and facility status will improve operations and maintenance. The analysis identifies deviations from schedule and provides potential solutions to dispatchers and drivers. Integrating this capability with the Traffic Control Service can help maintain transportation schedules and assure transfer connections in intermodal transportation. Information regarding passenger loading, bus running times, and mileage accumulated will help improve service and facilitate administrative reporting. Automatically recording and verifying performed tasks will enhance transit personnel management. Improved efficiency benefits transit providers and customers alike.

- **Personalized Public Transit**: Small publicly or privately operated vehicles operate on-demand assignments to pick up passengers who have requested service and deliver them to their destinations. Route deviation schemes, where vehicles would leave a fixed route for a short distance to pick up or discharge passengers, is another way of improving service under certain conditions. These transit vehicles can consist of small buses, taxicabs, or other small shared ride vehicles. They can essentially provide "door-to-door" service, expanding a route's coverage in less populated locations and neighborhoods. This service can potentially provide transportation at lower cost and with greater convenience than conventional fixed route transit.

- **Public Travel Security**: Systems monitor the environment in transit stations, parking lots, bus stops, and transit vehicles and generate alarms either automatically or manually as necessary. This improves security for both transit riders and operators. Transportation agencies and authorities can integrate this user service with other anti-crime plans.

Electronic Payment

- **Electronic Payment Services**: Will foster intermodal travel by providing a common electronic payment medium for all transportation modes and functions, including tolls, transit fares, and parking. A common service fee and payment structure, employing multi-use "smart cards," could integrate all modes of transportation including roadway pricing options. The flexibility electronic payment services offer will have an impact on travel demand management. In particular, they will enable relatively easy application of road pricing policies and could significantly influence departure times and mode selection. Electronic payment's primary benefit is convenience for all travelers and transportation providers.

Commercial Vehicle Operations

- **Commercial Vehicle Electronic Clearance**: This service will enable transponder-equipped trucks and buses to have their safety status, credentials, and weight checked at mainline speeds. Vehicles that are safe and legal and have no outstanding out-of-service citations will be allowed to pass the inspection/weight facility without delay.

  By working with Mexico and Canada, a more efficient traffic flow would be provided at border crossings and the deployment of technologies in these countries could ultimately prevent overweight, unsafe, or improperly registered vehicles from entering the United States. Truckers, shippers, and regulators will all benefit from improved productivity.

- **Automated Roadside Safety Inspection**: Automated roadside inspections would allow "real-time" access at the roadside to the safety performance record of carriers, vehicles, and drivers. Such access will help determine which vehicle or driver should be stopped for an inspection, as well as ensuring timely correction of previously identified problems.

  It would, for example, allow for more rapid and accurate inspection of brake performance at the roadside. Through the use of sensors and diagnostics, it would efficiently check vehicle systems and driver requirements and ultimately driver alertness and fitness for duty. Improved safety benefits truckers, shippers and regulators.

- **Commercial Vehicle Administrative Processes**: Electronically purchasing credentials would provide the carrier with the capability to electronically purchase annual and temporary credentials via computer link. It will reduce burdensome paperwork and processing time for both the states and the motor carriers.

  For automated mileage and fuel reporting and auditing, this service would enable participating interstate carriers to electronically capture mileage, fuel purchased, trip, and vehicle data by state. It would also automatically determine mileage traveled and fuel purchased in each state, for use by the carrier in preparing fuel tax and registration reports to the states. Currently, the administrative burden on carriers to collect and report mileage and fuel purchased within each state is significant. This service would significantly reduce the cost for collecting both types of data.

- **Onboard Safety Monitoring**: Onboard systems would monitor the safety status of a vehicle, cargo, and driver at mainline speeds. Vehicle monitoring would include sensing and collecting data on the condition of critical vehicle components such as brakes, tires, and lights, and determining thresholds for warnings and countermeasures. Cargo monitoring would involve sensing unsafe conditions relating to vehicle cargo, such as shifts in cargo while the vehicle is in operation. Driver monitoring is envisioned to include the monitoring of driving time and alertness using non-intrusive technology and the development of warning systems for the driver, the carrier, and the enforcement official. A warning of unsafe condition would first be provided to the driver, then to the carrier and roadside enforcement officials and would possibly prevent an accident before it happens. This service would minimize driver and equipment-related accidents for participating carriers.

- **Commercial Fleet Management**: The availability of real-time traffic information and vehicle location for commercial vehicles would help dispatchers to better manage fleet operations by helping their drivers to avoid congested areas and would also improve the reliability and efficiency of carriers' pickup-and-delivery operations. The benefits from this service would be substantial for those intermodal and time-sensitive fleets that can use these Intelligent Vehicle Highway System technologies to make their operations more efficient and reliable.

- **Hazardous Materials and Incident Notification**: Enhances the safety of shipments of hazardous materials by providing enforcement and response teams with timely, accurate information on cargo contents to enable them to react properly in emergency situations. The system would focus on determining when an incident involving a truck carrying hazardous material occurs, the nature and location of the incident, and the material or combination of materials involved so that the incident can be handled properly.

Emergency Management

- **Emergency Vehicle Management**: This user service includes three capabilities: fleet management, route guidance, and signal priority.

Fleet management will improve the display of emergency vehicle locations and help dispatchers efficiently task the units that can most quickly reach an incident site. Route guidance directs emergency vehicles to an incident location. Signal priority clears traffic signals in an emergency vehicle's route. Primary users include police, fire, and medical units.

- **Emergency Notification and Personal Security**: This service includes two capabilities: driver and personal security and automatic collision notification. Driver and personal security capabilities provide for user initiated distress signals for incidents such as mechanical breakdowns and carjackings. Automatic collision notification identifies a collision and automatically sends information regarding location, nature, and severity to emergency personnel.

Advanced Vehicle Safety Systems

- **Longitudinal Collision Avoidance**: Helps reduce the number and severity of collisions. It includes the sensing of potential or impending collisions, prompting a driver's avoidance actions, and temporarily controlling the vehicle.

- **Lateral Collision Avoidance**: Provides crash warnings and controls for lane changes and road departures. It will help reduce the number of lateral collisions involving two or more vehicles, or crashes involving a single vehicle leaving the roadway.

  For lane changes, a situation display can continuously monitor the vehicle's blind spot and drivers can be actively warned of an impending collision. If needed, automatic control can effectively respond to situations very rapidly. Warning systems can also alert a driver to an impending road departure, provide help in keeping the vehicle in the lane, and ultimately provide automatic control of steering and throttle in dangerous situations.

- **Intersection Collision Avoidance:** Warns drivers of imminent collisions when approaching or crossing an intersection that has traffic control (e.g., stop signs or traffic signals). This service also alerts the driver when the right-of-way at the intersection is unclear or ambiguous.

- **Vision Enhancement for Crash Avoidance**: Improved visibility would allow the driver to avoid potential collisions with other vehicles or obstacles in the roadway, as well as help the driver comply with traffic signs and signals. This service requires in-vehicle equipment for sensing potential hazard, processing this information, and displaying it in a way that is useful to a driver.

- **Safety Readiness**: In-vehicle equipment could unobtrusively gauge a driver's condition and provide a warning if he or she is drowsy or otherwise impaired. This service could also internally monitor critical components of an auto beyond the standard oil pressure and engine temperature lights. Equipment within the vehicle could also detect unsafe road conditions, such as bridge icing and standing water on a roadway, and provide a warning to the driver.

- **Pre-Crash Restraint Deployment**: Identifies the velocity, mass, and direction of the vehicles and objects involved in a potential crash and the number, location, and major physical characteristics of any occupants. Responses include tightening lap-shoulder belts, arming and deploying air bags at an optimal pressure, and deploying roll bars.

- **Automated Vehicle Operation**: Automated vehicle operations are a long term goal of Intelligent Transportation Systems which would provide vast improvements in safety by creating a nearly accident free driving environment. Drivers could buy vehicles with the necessary instrumentation or retrofit an existing vehicle. Vehicles that are incapable of automated operation during some transition period, will drive in lanes without automation.

These 28 user services have evolved from six major system areas:

- **Advanced Traffic Management Systems (ATMS)**: Permit real-time adjustment of traffic control systems and variable signing for driver advice. Applications in selected corridors have reduced delay, travel time, and accident incidence. ATMS uses coordinated signaling systems, video surveillance of corridors, ramp metering, automated toll collection, and variable message signs (VMS).

- **Advanced Traveler Information Systems (ATIS)**: Deal with the acquisition, analysis, communication, presentation, and use of information to assist the surface transportation traveler in moving from origin to destination in the way which best satisfies the traveler's needs for safety, efficiency, and comfort. Travel may involve a single mode or linked, multiple modes. These systems will let travelers know their locations and how to find services, and will permit communication between travelers and ATMS for continuous advice on traffic conditions and alternate routes. In addition, ATIS provides the driver with warnings related to road safety.

- **Commercial Vehicle Operations (CVO)**: Expedite deliveries, improve operational efficiency, improve incident response, and increase safety. CVO makes use of ATIS features critical to commercial and emergency vehicles. A primary goal of CVO is to reduce regulatory burdens and inefficiency. Many of the technologies related to CVO are already available in the marketplace. Automatic Vehicle Identification (AVI) devices are used in several locations to allow the electronic transfer of funds so travelers can pay tolls without stopping. GPS and Loran-C technologies can be used to track the location of individual vehicles for fleet management. Weigh-in-Motion (WIM), combined with Automatic Vehicle Classification (AVC), sorts vehicles for weight inspections. Onboard computers are available to monitor track performance.

- **Advanced Vehicle Control Systems (AVCS)**: Enhance the control of vehicles by facilitating and augmenting driver performance and, ultimately, relieving the driver of most tasks on designated, instrumented roadways. AVCS includes vehicle- and/or roadway-based electromechanical and communications devices.

- **Advanced Public Transportation Systems (APTS)**: Work in conjunction with ATMS and ATIS to provide mass transportation users and operators (e.g., buses, vanpools, high-occupancy vehicle (HOV) lanes, carpools, taxi cabs) with up-to-date information on status, schedules, and availability of public transit systems. Automatic vehicle location and monitoring systems will provide information to improve fleet management and inform riders of their connections. Electronic fare media will reduce the inconvenience of cash handling, provide new marketing data, and integrate third party billing for transit services. New HOV priority schemes using Intelligent Transportation Systems technologies will be devised and monitored automatically to enforce HOV facility use. Other examples of diverse transit applications are fixed routine transit, demand responsive transit, transit mobile supervisors, and passenger/consumer information.

- **Advanced Rural Transportation Systems (ARTS)**: Would include navigation aids, accident and incident response, information on dangerous road conditions, environmental conditions, farming activities, road maintenance, and railroad crossing information.